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THE HELEN IRON MINE, MICHIPICOTEN.

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INTRODUCTION.

Iron ranges belonging to the upper part of the Keewatin System have been found from point to point across the whole of northern Ontario, but up to the present only one mine of importance has been developed on any of these ranges, the Helen mine, eleven miles by rail northeast of Michipicoten harbor on Lake

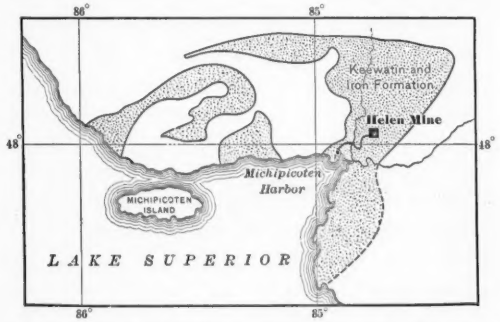

FIG. 36. Map showing the location of the Helen iron mine and the area of iron-bearing rocks in the Michipicoten region.

Superior. The Helen Iron Formation has naturally been compared with iron ranges of similar geological age in the United States, especially the Vermilion range in Minnesota, and there

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are many points of resemblance between the two, though there are also features of the Michipicoten range which differ greatly from those of the Vermilion range. In this account of the Helen mine special stress will be laid on the points in which it differs from the mines of other iron ranges.

Soon after it was opened the geology of the Helen mine and its surroundings was mapped and described by Prof. A. B. Willmott and present writer for the Bureau of Mines of Ontario[1]; but subsequent mining operations have added much to our knowledge of the deposit and have given occasion to modify some of the views expressed in that report.

TOPOGRAPHIC FEATURES.

As to topography the Helen mine occupies the east end of a narrow east and west trough half a mile long with a steep ridge rising about 200 feet on each side, and a precipitous hill 500 feet high closing the valley to the east. This narrow trough contains two ponds, each about a quarter of a mile long, called Sayer's and Boyer lakes. The ore body lies at the east end of the latter pond, which is the higher of the two and has now been pumped out, giving one an opportunity to see that the basin, 136 feet deep, is completely enclosed by rock. The same is true of Sayer's Lake which is still full of water. There can be no doubt that the hollowing of these two rock basins was connected with the processes by which the ore was deposited. In earlier days the ore rose as a rusty looking mound about 100 feet above Boyer Lake, with the steep "Hematite Hill" rising 400 feet higher behind it; but this ore has been removed and mining is now going on to a depth of about 280 feet below the original level of the pond, which stood 600 feet above Lake Superior.

GEOLOGY

The Helen Iron Formation is widely distributed in the Michipicoten district as comparatively short strips separated from one another by older rocks; the part in which the mine occurs is a mile and three quarters long from east to west with a greatest

[1] An. Rep., 1902, pp. 152–184.

width of about 1,000 feet. The peculiar trough mentioned above occupies the western end of this portion of the range, the eastern end rising as a ridge well above the surrounding country, with a flanking of Keewatin schist toward the south.

The formation consists essentially of banded siliceous material along the northern side of the trough and of impure siderite along the southern side, the latter passing into green schist of the Wawa Tuffs. The formation is therefore unsymmetrical.

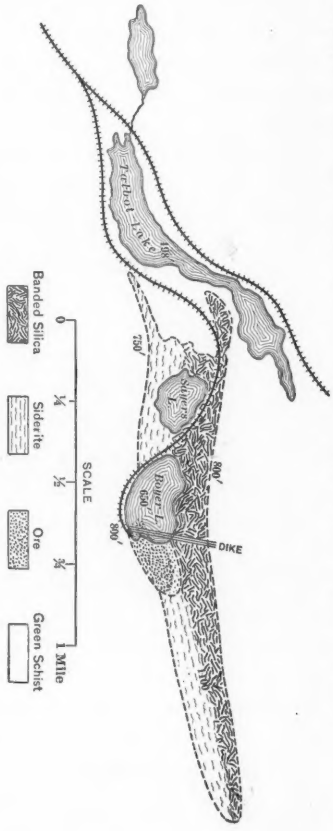

FIG. 37. Sketch map showing the location and geology of the Helen iron mine and vicinity.

The enclosing green schists have toward the west a synclinal form slightly contorted by a little upward bend toward the southwest side of Sayer's Lake, but on the whole canoe-shaped, with a pitch toward the east as seen in the basins of the two ponds, but probably with a pitch toward the west at the opposite end, which is not so well exposed. Diamond drilling shows that ore goes 300 feet below the old level of Boyer Lake, so that the canoe-shaped syncline of green schist has at least that depth in the middle. The difference in the topography of the two ends of this small syncline is very marked, the west end enclosing deep

rock-basins carved in the iron formation, while in the middle the same rocks rise as the highest hill in the region, 636 feet above the bottom of Boyer Lake, and the east end forms a somewhat lower but still lofty ridge. Fig. 38 gives a cross section of this syncline.

A large dike of diabase crossing the syncline from north to south just west of the main ore body probably had some influence on its deposition, but too much stress should not be placed

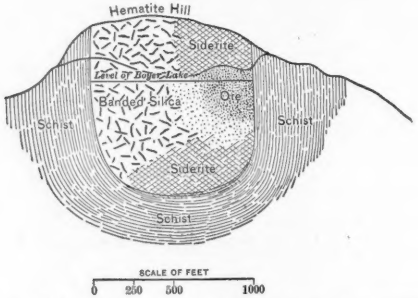

FIG. 38. Cross-section of the Helen iron mine showing position of the ore in the upper portion of the ore-bearing rock.

on this, since a considerable mass of ore is found to the west of the dike also. These relations will appear from the east and west section, Fig. 39; also from the southeast cross-section, Fig. 38.

ROCKS OF THE IRON FORMATION.

The rocks of the Helen Iron Formation are of an unusual kind and should be described somewhat in detail, since they have doubtless been the source of the ore. The siliceous rock along the north side of the syncline cannot be called jasper or chert, since it has the appearance of a fine-grained banded sandstone, the bands being a quarter of an inch to two inches in thickness, some white and sugary, others brownish, and still others dark gray. Thin sections show that the sugary quartz, whose grains are often so feebly cemented that they rub off under the finger,

consists of anhedra fitting closely together and not of rounded particles. The brown bands contain some siderite and the dark gray bands a little magnetite; but the rock is distinctly poor in iron and has little effect on the compass. Much of the banded silica has been crushed and then cemented into a coarse breccia.

The siderite forms massive beds of rock passing toward the south into sericite schist. Under the microscope one finds in it grains of quartz like those described above, and with the naked eye one can see that small crystals of pyrite are scattered through it. The purest specimens analyzed contain 5 to 10 per cent. of silica and a small percentage of magnesia and lime, so that the amount of iron scarcely rises above 35 per cent. The total amount of iron contained as carbonate in the ridge east of the mine must however be very great, and the amount removed from the western end of the syncline may have been equally great. In the purest part of the siderite pyrite is present only in small proportions, but in other places, as at the outlet of Boyer Lake, into Sayer's Lake, the amount may increase till it makes up half the rock or more.

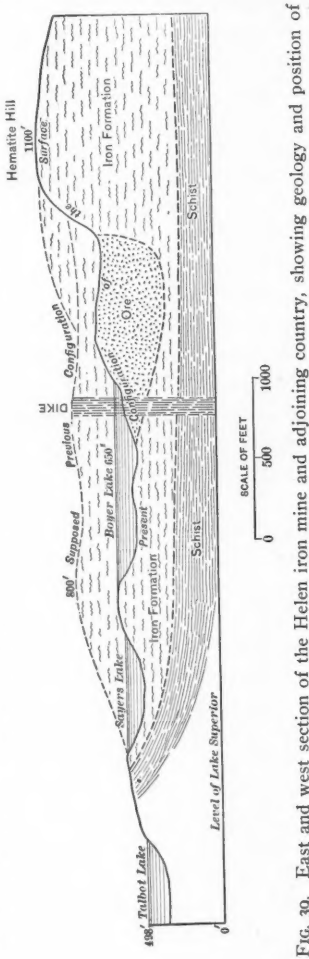

FIG. 39. East and west section of the Helen iron mine and adjoining country, showing geology and position of the ore-body in the iron formation.

On the south shore of Sayer's

Lake bands several feet thick of very pyritous rock contain granular silica instead of siderite. With the pyrite there is sometimes also pyrrhotite, which weathers very rapidly, while the pyrite is comparatively slow to change.

A little slate, with holes from which pyrite has weathered and with a good deal of granular silica, accompanies the other rocks, but can have had little effect on the deposition of the ore.

The most striking features of the iron ranges as a whole are the relatively large quantities of siderite and of pyrite as compared with banded silica. These two materials seem to have been the chief sources of the ore.

The relations of the banded silica and siderite are not entirely clear. In places they grade into one another, but part of the siderite is later than the banded rock, since the fragments in the breccias are often cemented with impure siderite. On the other hand the presence in the siderite of granules of silica having the same character as those of the other rock suggest that silica was in solution while the siderite was being deposited.

THE ORE-BODY.

The Helen ore is mainly limonite with a little red hematite intermixed, in structure generally porous and concretionary, occasionally forming stalactites. The ore shipped last summer ran from 55.15 to 60.56 per cent. of iron, the latter percentage indicating the presence of some hematite, and contained 4.32 per cent. of moisture, with phosphorus somewhat above the bessemer limit and 0.09 per cent. of sulphur. It is easily mined except for one curious and unfortunate feature, the occurrence of pockets or layers of pyrites in unexpected places. The gradation between ore and pyrite is rapid, so that good ore free from sulphur may be mined within a foot or two of a mass of pyritic sand made up chiefly of little crystals of pyrite with a small amount of sandy-looking, granular silica. These pyrite masses may be of all sizes up to hundreds of tons, and it has even been proposed to mine the larger ones separately for use in generating sulphurous acid for pulp making.

The ore-body lies on the south side of the syncline in the por-

tion probably occupied by siderite in the beginning; it grows leaner toward the north, and passes into brecciated banded silica too poor to work. Fragments of the banded silica may be found enclosed in ore as if silica had been replaced by limonite, and there is evidence, in the shape of secondary deposits of brown jasper, that silica has passed into solution since the ore began to be deposited. To the south the ore is separated from green schist by a sheet of "paint rock." The ore-body is elongated from east to west, ends against the foot of a cliff of impure siderite toward the east and does not extend westward much beyond the diabase dike which cuts off the eastern end of the basin of Boyer Lake. In the 300 feet of depth through which the ore has been followed there has been little change in the length or breadth of the ore-body, though there seems a tendency to dip beneath the siderite hill to the east. The pockets of pyrite increase in number at lower levels, but the character of the clean ore has not changd in depth. Last summer it was estimated by the efficient manager of the mine, Mr. Seeley, that 1,500,000 tons of ore had been shipped and that probably at least 1,000,000 tons of similar ore remained to be mined.

ORIGIN OF THE ORE.

There are several interesting questions which may be asked as to the origin of the Helen ore-body:

How was the basin formed in which the ore was deposited? Why are there rock basins at the west end of the iron range, and not at the east end? What was the chief source of the ore and how was it dissolved and afterward precipitated?

The remarkable rock basins of Boyer and Sayer's Lakes can be accounted for only by solution. The steep cliffs to be seen rising on the north and south sides of Boyer Lake basin since it has been pumped out consist of rocks very difficultly soluble, banded silica and green schist, but at its outlet a cliff of impure pyritous siderite seems readily enough attacked. One may suppose, however, that for some reason the iron formation of the basin, especially the southern sideritic part, was considerably shat-

tered so that fluids could circulate through it. Carbonic acid from the overlying soil or sulphates or free sulphuric acid formed by the weathering of pyrites seem competent solvents to remove all but the grains of silica in the siderite if there were channels for water to percolate through the mass. At first the solvents may have acted on shattered siderite at considerable depths and with a comparatively high temperature, so that silica also passed into solution and was removed from the basin.

Later the overlying materials were dissolved and the basin became open to the air, somewhat as at present. Then oxidation became more active and iron was precipitated from its solutions, chiefly as limonite. During the removal of the siderite the less soluble pyrite crystals were not much attacked and accumulated, with grains of silica from the siderite, as the sheets and pockets of pyrite sand now found in the ore. With free access of oxygen the pyrite masses oxidized more rapidly than before and furnished part of the ore.

We may suppose that Hematite Hill, formed largely of the same impure siderite as supplied the ore in the basin at its foot to the west, remained unfissured so that it could be attacked by solvents only on the surface and very slowly, as at the present day.

That iron is still being dissolved and precipitated is proved by the yellow ocher found as mud at the east end of the Boyer Lake basin, and by the coating of hard limonite on drift boulders evidently left in the basin during the Ice Age.

It seems probable that siderite provided most of the ore, but pyrite undoubtedly supplied a very considerable portion also; while there is no evidence to show that the banded silica played any important part in the work.

It will be observed that the basin in which the ore was deposited is of a different type from that found in most of the orebodies south and west of Lake Superior. It is not at the lower end of a pitching trough or in a pocket cut off by dikes, but is near the middle of a canoe-shaped syncline with unchanged rocks of the iron formation as its lower limit (see Fig. 38). The only

dike found is not on the lower side of the ore but near its upper end, and some ore extends beyond it, so that it seems to have had little effect as enclosing a basin; but it may be that shattering of the iron formation when the dike came into place was the real cause of the depth of the basin just to the east and hence of the deposit of the ore-body at that particular place.

METASOMATIC PROCESSES IN THE GOLD DEPOSITS OF WESTERN AUSTRALIA.[1]

WALDEMAR LINDGREN.

Western Australia forms a tableland of moderate elevation surmounted by short and low ridges. Crystalline schists and granites are the principal rocks of which this plateau is constructed. The schists extend with general north-south strike and vertical or steep dip across the whole central part of the State and consist largely of amphibolites, massive or foliated, which have been derived by metamorphism from a basic rock like diorite, gabbro or diabase. There are also highly altered sedimentary rocks such as quartzites, slates, etc., more rarely limestones. At Kalgoorlie, for example, slates are intimately associated with amphibolites, and on a more extensive scale these altered sediments are developed in the Pilbara district[2] on the northern coast; from this place they are described by Mr. Maitland as the Mosquito Creek beds.

Granitic rocks also enter extensively in the complex of crystalline schists; they vary much in composition, and texture, and a large part of them show gneissoid structure. The granites, granite-porphyries, and gneisses form large areas and frequently adjoin the amphibolites, as shown, for instance, by Mr. Jackson[3] in the Mt. Morgans district, about 150 miles north of Kalgoorlie. Lenticular masses of amphibolite are contained in the granitic rocks and vice versa, so that the sequence of the rocks is not always clearly apparent. Mr. Maitland, however, believes that many of the granitic rocks are intrusive into the amphibolites.

[1] The incentive to the preparation of this paper was a suite of fine specimens of ores from the Ivanhoe and the Oroya-Brownhill mines obtained through the kindness of Mr. H. C. Hoover. A study of the valuable reports by Messrs. Maitland, Simpson and Jackson, of the Geological Survey of Western Australia, added to my desire to bring out certain salient points in the metasomatic history of the deposits.

[2] A. Gibb Maitland, Bull. 20, p. 28, Geol. Sur. of West. Austr., 1905.

[3] C. F. V. Jackson, Bull. 18, Geol. Sur. West. Austr., 1905.

The age of neither the igneous and sedimentary schists nor the intrusives is definitely known, but it is considered to be pre-Cambrian. Toward the northwest coast they disappear beneath transgressing Carboniferous limestones lying horizontal and with great unconformity on the crystalline schists.[1] In the Pilbara district the schists are unconformably overlain by the Nullagine series of sandstones, conglomerates and limestones, with associated effusives. Mr. Maitland assigns this series provisionally to the Cambrian, but it contains no fossils.

In the Kimberley district, which is situated in the extreme northern part of the State, a very complete geological column has been recognized, ranging from the Cambrian through the Devonian to the Carboniferous; this section is, however, outside of the principal gold belt.

The gold deposits are contained chiefly in the amphibolites but also, though less commonly, in the granitic rocks. Mr. Maitland says:[2]

"All the important auriferous areas occur within the limits or in the immediate vicinity of country occupied by the schistose rocks. These auriferous belts occupy a very large area of country, extending from the South Coast . . . to the North West Coast, extending over about 14 degrees of latitude. The auriferous belts exceed twenty miles in width in places. There is a larger area of auriferous country exposed at the surface than in any other portion of Australasia."

The center of mining activity is, as well known, at Kalgoorlie, about 350 miles east of Perth. From the mines within the so-called "Golden Mile" at that place the larger part of the output of Western Australia has been derived, although other mines north and northwest of Kalgoorlie now contribute a considerable amount to the production of the State. The most prominent among these outside mines are the Westralia Mt. Morgan and Sons of Gwalia in the Mt. Margaret Gold Field, and the Great Fingall in the Murchison Gold Field, 300 miles northwest of Kalgoorlie. The total gold production of Western Australia

[1] A. Gibb Maitland, Bull. 4, p. 15, Geol. Sur. West. Austr.
[2] Bull. 4, Geol. Sur. West. Austr., p. 25.

from 1886 to 1904, inclusive, is given by the Director of the U. S. Mint in his report upon the production of precious metals, as $267,001,773.

The geologists of Western Australia distinguish three modes of occurrence of gold-bearing lodes:

1. The "hematite-bearing quartzites." These occur very commonly in the amphibolites in all the gold fields and form prominent outcrops parallel in strike and dip to the schistosity of the rock. They are from a few feet up to a couple of hundred feet wide and consist of banded quartz, hematite and magnetite, with a little pyrite; sometimes also ilmenite. Mr. Maitland says "they appear to be merely highly altered bands of foliated greenstone and in some places can be seen to tail out imperceptibly into the latter."[1] They usually contain a little gold, but not sufficient to make them payable. They are earlier than the quartz veins proper, for these cut across the "hematite-bearing quartzites" and are often enriched at the point of intersection. Further reference to these deposits will be found below.

2. The second class consists of the normal quartz veins which usually occur in the amphibolite or along the contact of granitic rocks and amphibolite. Some of them, however, cut through granite. On the whole the veins conform in strike and dip with the steeply-dipping schists, but many exceptions from this rule occur. The veins are usually short, or branched and curved; and the quartz has great tendency to form lenticular ore-bodies. This is especially well shown by the maps of the Westralia, Mt. Morgan[2] mines reproduced in one of the recent bulletins of the Geological Survey. Minerals accompanying the native gold are[3] galena, blende, pyrrhotite, chalcopyrite, arsenopyrite, stibnite, bismuthinite, pyrite, and scheelite, chlorite, calcite, and sericite. In addition tourmaline is reported from one mine, the Sons of Gwalia.[4]

This class of deposits has probably in most cases been formed

[1] Bull. 14, p. 18.
[2] C. F. V. Jackson, Bull. 18, Geol. Sur. of West. Austr.
[3] E. S. Simpson, Bull. 6, Geol. Sur. West. Austr., p. 20.
[4] C. F. V. Jackson, Bull. 13, Geol. Sur. West. Austr., p. 29.

by filling of open cavities; the veins are often bent, corrugated, and deformed. At Mt. Morgan the quartz bodies form solid pipes of lenticular section, the main axes of which dip 45° to the south. The oreshoots within these lenses or lineals also have a southerly trend.

3. The quartz lenses are at many places surrounded by altered country rock; when the latter prevails transitions are formed to the third class or replacement deposits, to which the name "lode formations" is given.[1]

Mr. Simpson describes the lode formation in the following words:

"A lode formation may be defined as a more or less vertical zone of rock, usually continuous with the surrounding rock, and of similar origin, but distinct from it in carrying metallic ores disseminated through it in payable quantities, and, as a rule, characterized by strong foliation. Deposits of this nature are probably deep-seated; at Kalgoorlie mining operations have already proved their persistence to 1,500 feet below the surface. The typical lode formations probably owe their origin to a shearing action having crushed and foliated portion of a rock mass in a certain definite direction, producing a more or less well-defined band of rock through which, by virtue of the foliation, mineral-bearing solutions or vapours can have free circulation. In consequence of this, mineral deposits are formed within the rock, usually, but not necessarily, extending over the whole of the foliated zone, but seldom beyond it, and having no definite boundaries horizontally or vertically other than those determined by the decrease of the assay value of the rock in any one direction to a point at which it ceases to pay the expenses of working.

"The most notable development of deposits of this description is to be found at Boulder, the Southern portion of the Kalgoorlie belt. From there something over two million ounces of gold have been taken in the last seven years. In this area the rocks consist mainly of amphibolites (altered in various ways, but

[1] E. S. Simpson, Bull. 6, Geol. Sur. West. Austr., p. 22. Karl Schmeisser (Die Goldfelder Australasiens) described them as "zusammengesetzte Gänge," or composite veins.

largely into massive chloritic rock and chlorite schist), together with some smaller bodies of porphyrite, felsite, slate, and quartzite. The lode formations consist almost entirely of vertical or steeply inclined zones of chlorite schists, or foliated greenstone often passing insensibly into unaltered greenstone on either side, but sometimes showing an irregular boundary. They vary in width from 2 or 3 feet up to 80 feet, and carry disseminated grains of gold, calaverite, and other secondary minerals."

Of minerals associated with the native gold, tellurides prevail, and among these calaverite and coloradoite (telluride of mercury) are the most common. Pyrite is abundant, but almost always finely divided in contrast to the often massive tellurides. Further accessory minerals are chalcopyrite, blende, galena, pyrargyrite, enargite, löllingite, fluorite, magnetite, rutile, calcite, dolomite, siderite, ankerite, sericite, chlorite, and roscoelite.[1] To these tourmaline and albite should be added. Here, too, the orebodies form lenticular bodies, as recently shown by Mr. H. C. Hoover in an article in the Engineering and Mining Journal; they have usually a rich core from which the values decrease outward, and are of large dimensions. Mining operations have attained 1,900 feet, at which depth some of the mines are still in ore.

In appearance the ore varies from a dark green distinctly chloritic, foliated schist, as in the Oroya-Brownhill mine, to pale green sericite schists and to banded or massive dark rocks, flinty in places and ranging from dark green to gray or brown. Small specks of pyrites are distributed through the ores, and they contain bright yellow gold associated with much pale yellow calaverite and black, lustrous coloradoite with semi-conchoidal fracture. In places the tellurides and gold have developed as seams several centimeters thick, in joint planes crossing the schistosity.

Some of the ores contain, as stated, chloritic material, the mineral forming bright-green aggregates associated with fine-grained quartz, dolomite, and sericite. In descriptions of the less altered rocks ilmenite partly altered to leucoxene is frequently

[1] Bull. 6, Geol. Sur. West. Austr., p. 21.

mentioned. Other specimens of normal ore show under the microscope principally calcite, siderite and dolomitic carbonates of very variable size of grain and containing nests and lenses of fine-grained quartz as well as minor amounts of sharply-defined foils of sericite. The carbonate grains enclose irregular masses of tellurides and coarse gold, while on the other hand some of the larger masses of calaverite enclose sharply-defined rhombohedrons of carbonates.

In other cases the quartz predominates in interlocking grains of rapidly varying size and contains enclosed small irregular masses of gold and telluride. Ill-defined areas of very fine-grained quartz mingled with sericite, pyrite, and carbonates undoubtedly represent imperfectly replaced fragments of country rock. A bright green mica—possibly fuchsite—sometimes replaces the sericite; it is not roscoelite, though this mineral is also reported present at Kalgoorlie.

Tourmaline in dark brown roughly idiomorphic prisms was observed in several sections, directly associated with the tellurides and gold. Its presence at Kalgoorlie is not noted by the Australian geologists, but it has been signalized by Mr. L. J. Spencer,[1] who says that it is embedded as black needles, 2 to 3 mm. long in pyrite and in the rock.

The presence of magnetite in the ores is noted by Mr. Simpson,[2] and more distinctly by Professor Spencer, who found several crystals 1 cm. in diameter, embedded in tellurides of one specimen from Kalgurli mine.

Other specimens from the Ivanhoe are foliated rocks containing a large amount of granular or partly idiomorphic albite, many grains of which show twin lamellæ. Streaks of pyrite emphasize the schistose structure. Quartz, calcite, and sericite, as well as native gold and a little specularite, are also present. The albite was undoubtedly formed at the same time as the other vein minerals. Analogous occurrences of albite are those at the Treadwell mine, Alaska, and in the California and Victorian

[1] Mineralogical notes on Western Australian tellurides. Mineralogical Magazine, XIII., pp. 268–290. London, 1901–1903.

[2] Bull. 6, Geol. Sur. West. Austr.

(Bendigo) quartz veins, though at the two last-named places it also appears as part of the quartz filling of the veins.

Microscopic examination of the ores of Kalgoorlie were made by Mr. G. W. Card,[1] whose conclusions were that the ores were derived from an acid eruptive rock; this conclusion should probably be modified. Previous to this Mr. Göczel and Dr. K. Vogelsang[2] had examined the rocks and considered them as altered diabases. Mr. Edward S. Simpson[3] has clearly shown that the ores are derived from the amphibolites which cover such large areas in the State.

From the many analyses of the unaltered or little altered amphibolites given by Mr. Simpson the following two are selected:

ANALYSES OF AMPHIBOLITES FROM KALGOORLIE.

	3231	1936		3231	1936
SiO_2	48.86	57.72	K_2O	.19	.12
Al_2O_3	14.91	9.68	H_2O—	.04	.16
Fe_2O_3		6.49	H_2O+	1.51	1.51
FeO	11.13	9.17	TiO_2	.22	1.13
MgO	7.65	1.63	CO_2	none.	1.84
CaO	12.19	5.05	MnO	.90	.09
Na_2O	2.58	3.92		100.18	98.51

3231. Star of Colac. Bull. 6, Geol. Sur. West. Austr., p. 67. Analyst, C. C. Williams.

"Rock consists of coarse-grained mixture of feldspar and chlorite. It contains colorless hornblende, saussurite with clear mosaic of albite, also ilmenite surrounded by leucoxene."

1936. Hannans main shaft, at depth of 600 feet. Analyst, C. C. Williams.

"Rather coarse-grained rock containing hornblende, chlorite, feldspar (albite?), ilmenite and secondary quartz."

[1] Records of the Geological Survey of New South Wales, Vol. IV., Pt. I., Sydney, 1898, pp. 17–43.

[2] K. Schmeisser, Die Goldfelder Australasiens, p. 44.

[3] Bull. 6, Geol. Sur. West. Austr., p. 65.

Analysis 3231 is probably fairly representative of many amphibolites of Western Australia. It contains no free quartz and is rich in lime and iron. There is very little potash, and only 2.58 per cent. of soda.

Analysis 1936 is somewhat more altered, but the proportion of alkalies is about the same. There are about 4 per cent. of carbonates and probably about 20 per cent. of free, secondary quartz.

The following three analyses, also given by Mr. Simpson, show the composition of the ores:

ANALYSES OF ORES FROM KALGOORLIE.

	206	1753	1751
SiO_2	51.27	46.94	42.01
Al_2O_3	13.85	12.49	8.42
Fe_2O_3	1.54	.33	2.45
FeO	2.63	9.20	15.76
MgO	4.18	3.56	1.67
CaO	6.40	6.43	7.07
Na_2O	1.78	1.84	2.62
K_2O	2.37	2.57	1.15
H_2O-[1]	.40	.09	.23
H_2O+[2]	.22	.30	.67
TiO_2	.23	.14	.81
CO_2	8.02	13.41	15.65
P_2O_5	trace.		
Te	trace.		
FeS_2	8.41	2.28	.30
MnO	trace.	.32	.41
	101.30	99.87	99.22

206. 300-foot level, Lake View Consols mine. Analyst, E. S. Simpson. Bull. 6, Geol. Sur. West. Austr., pp. 23 and 67.

"Strongly foliated, gray lode stuff. Assay, 9 oz. 12 dw. of gold and 6 oz. 7 dw. of silver per ton. It shows chlorite and sericite on the cleavage planes."

1753. A foliated greenish-gray lode stuff from the 400-foot level, Ivanhoe mine. Analyst, C. G. Gibson. Bull. 6. Geol. Sur. West. Aust., pp. 23 and 67.

"Contains chlorite, carbonates, a feldspathic material,

[1] Hygroscopic.

[2] Combined.

ilmenite, and some quartz. Trace of gold and no silver."

1751. Siderite rock, W. cross-cut 400-foot level, Ivanhoe mine. Analyst, C. G. Gibson. Bull. 6, Geol. Surv. West. Austr., p. 67.

"Gray, compact rock, containing carbonates, grains of quartz and of black iron ores, . . . altered feldspar and some scaly, green chlorite."

The analyses may be roughly recalculated as follows:

PROBABLE MINERAL COMPOSITION OF ORES FROM KALGOORLIE.

	206	1753	1751	Remarks.
Quartz	29.52	25.20	21.44	
Chlorite	6.86	2.76	2.94	$FeO.4\ MgO.Al_2O_3.3SiO_2.4H_2O$.
Albite	15.12	15.70	22.12	
Sericite	19.54	21.52	9.58	$K_2O.3\ Al_2O_3.6\ SiO_2.2\ H_2O$.
$CaCO_3$	11.42	11.50	12.61	
$MgCO_3$	4.20	5.38	1.76	
$FeCO_3$	2.32	14.60	23.20	
$MnCO_3$			.67	
Pyrite	8.41	2.25	.30	
Magnetite?		.47	3.53	
TiO_2	.23	.14	.81	
Fe_2O_3	1.54			
Al_2O_3	2.14	.61		
Hygroscopic water			.23	
	101.30	100.13	99.19	

At first glance the analyses of the altered rocks do not show very great changes as far as bases and silica are concerned. The principal differences are in the added carbon dioxide of the altered rocks, ranging from 8 to nearly 16 per cent., as well as in the reversal of the relations of the alkalies. In the fresh amphibolites of Western Australia there is generally only a fraction of one per cent. of potash as against 2 to 4 per cent. of soda, whereas in the altered rocks the soda averages only 2.5 per cent. and the potash has been increased to an average of 1.5 per cent.

There is less of combined water in the altered rocks than in the fresh, owing to the replacement of chlorite with about 13 per cent. of water by sericite with only 4 or 5 per cent. Nevertheless there seems to be a deficiency of water in 206 and 1753 and an

excess of alumina; analysis 206 is probably defective in some way, and the statements of the analysis on p. 23 and p. 67 of Bulletin No. 6 show some discrepancies. It is possible that the specimen contained kaolin as it was collected only 300 feet below the surface. Mr. Simpson suggests that kaolin may be present in 1751, but the calculation offers little support for this view.

The metasomatic processes consist then in the introduction of carbon dioxide and sulphur with gold, mercury and tellurium and the attendant development of carbonates at the expense of the lime, magnesia and iron contained in the chlorite and amphibole, and of pyrite at the expense of the same minerals and the black iron ores. The silica set free by the decomposition of the silicate has been deposited as quartz where it was not needed for the formation of the new silicates sericite and albite. The sericite does not prevail to the great extent usual in many silicate rocks adjoining gold-bearing veins; this appears to be due to the presence of large amounts of albite in the original amphibolites which feldspar evidently has been subjected to a process of solution and re-deposition just as in the metasomatic granites of Cripple Creek the orthoclase is dissolved and re-deposited as pure adularia by the metalliferous solutions. That albite is present in the altered rock is clear, but just how much of it is original and how much newly formed can not be said with certainty. The chlorite is in part residual, but the microscope shows definitely that some new chlorite also crystallizes in the quartz. Abundant carbonates form during the replacement; calcite and siderite predominate and the presence of large amounts of the latter mineral is noteworthy. The altered rocks seem to have lost some iron, but the lime and magnesia have probably changed but little.

The metasomatic processes at Kalgoorlie have transformed an amphibole-chlorite-zoisite-albite rock into a quartz-sericite-albite-carbonate rock. They do not always produce a uniform product, though the general trend of the reactions is in one direction. Altered rocks may be found in which secondary quartz predominates, others in which albite or sericite forms the prin-

cipal products, and still others rich in carbonate of iron, calcium and magnesium.

Regarding metasomatic processes in granitic rocks there are recorded two analyses of interest in the descriptions by Mr. A. Gibb Maitland of the Pilbara Goldfield.[1]

TABLE OF ANALYSES OF FRESH AND ALTERED GRANITES FROM PILBARA.

	5426	5395		5426	5395
SiO_2	63.08	69.97	K_2O	3.86	5.82
Al_2O_3	15.10	18.74	H_2O—[2]	.10	.05
Fe_2O_3	1.72	1.04	H_2O+[3]	.58	1.79
FeO	4.45	.43	CO_2	.11	none
MgO	2.67	.81	TiO	.68	.64
CaO	2.83	.15	FeS_2	.17	.....
Na_2O	4.37	.59	MnO	.23	trace
				99.95	100.03

5426. Granite. Mosquito Creek. Analyst J. H. Brooking. Intrusive into greenstone schists and micaceous schists.

5395. Greenish-gray, altered granite or lode stuff. Boodalyerri. Analyst, E. S. Simpson.

No. 5426 has approximately the composition of a granodiorite. In No. 5395 the same reversal of the relation between potash and soda is noted as in the case of the Kalgoorlie rocks. The altered rock has much potash and very little soda and is high in combined water; all this is no doubt due to the metasomatic development of sericite. In the absence of carbon-dioxide to take care of the alkaline earths and ferrous oxide, a strong leaching of these substances has occurred. The removal of the bases produces an apparent (probably not real) increase in alumina and silica. While the two specimens are not taken in juxtaposition it seems reasonably sure from the text that 5395 is an altered form of 5426.

The age of the Western Australian gold deposits is thought to be pre-Cambrian by the local geologists.[4] It is known that

[1] Bull. 15, Geol. Sur. West. Austr., p. 12.

[2] Hygroscopic.

[3] Combined.

[4] Mr. P. Krusch believes (Die Tellur Erze Westaustraliens, Zeitschrift fur prakt. geol. 9, p. 216, 1901) that the lodes carrying telluride ores may be

they are covered by Carboniferous beds and in the Pilbara district they are overlain by the Nullagine series of conglomerates which contains abundant fragments of quartz veins of the underlying schist and slate complex. These conglomerates which also contain some possibly detrital gold are thought to be of Cambrian age. On the other hand, the principal veins of the Kimberly district which is outside of the main belt, in the extreme north, occur in Cambrian sediments. The age of the gold deposit of Victoria and New South Wales is Silurian, and they were formed after extensive intrusions of granitic magma.

In the gold belt of Western Australia all the characters of the deposits point to genesis under conditions of great depth and dynamic metamorphism; the deposits, although occurring mostly in amphibolites and slates, are later than the granites intrusive in the former rocks, and are probably in closest genetic relations to the granites. Analogous occurrences are those in Victoria and California, where the gold veins are usually contained in the schists and slates, although they assuredly were formed closely after the intrusion of great masses of granitic magma.

Structurally there is great similarity between the gold deposits of Western Australia and the eastern part of the United States—the Appalachian belt. The lenticular shape is characteristic of both as it probably is of all such deposits formed during or before important epochs of dynamo metamorphism. There is a great difference between these veins and the clear cut, straight fissures of the California gold belt, for instance.

The presence of tourmaline, albite and smaller amounts of magnetite and specularite indicates, I believe, that the veins were formed at great depth below the surface and at comparatively high pressure and temperature. The metasomatic processes active in the veins of Kalgoorlie are almost identical with those characterizing similar deposits elsewhere, for instance, in the California gold belt and at Cripple Creek. The formation of carbonates, the concentration of potash as sericite and leaching

later than the ordinary gold quartz veins and in fact of Tertiary age, but the reasons given are not convincing. Telluride ores are certainly not confined to Tertiary deposits as Mr. Krusch seems to believe.

of soda are normal phenomena, and point to a remarkable similarity of the gold-bearing solutions throughout the world.

In connection with the origin of the veins the low grade deposits, briefly described above as the "hematite-bearing quartzites," deserve a little more attention. These veins appear to be replacement deposits formed shortly before the normal veins which intersect them and are enriched by them. Their normal high content of magnetite, hematite, sometimes also titanic iron ore, together with their low tenor in gold,[1] indicates, I think, that they were formed under conditions of still higher temperature than the normal veins, possibly by the first highly heated waters arising from the granitic magmas. Moreover, it is shown by the Australian geologists that transitions exist between the two classes, as for instance in the case of Westralia Mt. Morgan.[2]

Interesting questions arise upon comparison of the pre-Cambrian Kalgoorlie deposits with those of Cripple Creek, which are of late Tertiary age. At both places gold tellurides occur on a large scale. At Cripple Creek, however, Mr. Ransome and myself have shown[3] that the deposition of these tellurides was largely in the nature of fissure filling, and that it was not a deep-seated process, but went on within or a short distance beneath the cone of a volcano at a moderate depth below the surface. At Cripple Creek it is the rule to find the tellurides in crystallized form, whereas at Kalgoorlie they are almost without exception in massive form. Tourmaline, magnetite, and albite do not occur in the Cripple Creek veins, but adularia is formed quite commonly together with sericite.

From these data it seems fair to draw the conclusion that tellurides of gold may be deposited in large quantities, both near the surface and at a depth of many thousands of feet below it. As far as Cripple Creek is concerned this is encouraging for the prospects of deeper mining.

[1] W. Lindgren, Ore deposition and deep mining. ECONOMIC GEOLOGY, Vol. I., No. 1, p. 44.

[2] Bull. 18, Geol. Sur. West. Austr.

[3] The Geology and Gold Deposits of the Cripple Creek District. Prof. Pap. 54, U. S. Geol. Sur., in press.

There are several very remarkable analogies between the two districts. Both were discovered about the same time, Cripple Creek a few years earlier than Kalgoorlie. In both the rich zone is confined within a very small area—within a square mile at Kalgoorlie, and within a few square miles at Cripple Creek. Both have produced similar amounts of gold: Kalgoorlie approximately 130 million dollars; Cripple Creek about 140 million dollars. In both, finally, the deeper workings, which at Cripple Creek have attained 1,500 feet, and in Kalgoorlie, 1,900 feet, have shown a diminished supply of ore. If the conclusion established above is true this decrease of quantity of ore at Cripple Creek can not be due to the gradual increase in pressure and temperature in depth during the ore deposition. It is much more probable that other causes were effective, such as rapid movement of the solutions in a few channels, contrasting with more stagnant conditions within extensively fissured and more open country nearer to the surface.

Neither is it probable that decrease of pressure and temperature appreciably influenced the deposition at Kalgoorlie within an interval of 1,000 or 2,000 feet. Here, also, the explanation of the ore shoots is perhaps rather to be sought in local causes favoring an intimate penetration of the rocks by slowly moving solutions.

In the Mother Lode district of California, from Angels Camp to Carson Hill and the Stanislaus River, are a number of large deposits, representatives of a certain type of the gold quartz veins of that State. The Utica, Lightner, and Melones mines are the best known of those working on these deposits. A comparison of the metasomatic processes active here with those of Kalgoorlie develops some interesting points to which sufficient attention has not been directed. The lodes are contained in amphibolites and amphibolite schists like those at Kalgoorlie, and are characterized by Mr. F. L. Ransome as follows:[1] They are "in the main complex stringer leads. But the country rock is usually much more altered and may be heavily impregnated with pyrite near the vein. It is often changed to a soft grayish rock consisting

[1] Folio 63, U. S. Geol. Survey, p. 8.

chiefly of carbonates of lime and magnesia with sericite and sometimes a little chlorite. Such altered and pyritized country rock is too poor in gold to pay for working alone, but is often run through the mills for the sake of the rich stringers which intersect it. These veins are usually richer in carbonates than those in the black slate areas, and in certain parts of the district are rich in tellurides." Mr. Ransome further mentions the occurrence of albite in the quartz filling of the veins, as well as in the ore resulting from the replacement of the amphibolite, and describes the tellurides, coloradoite, petzite, hessite, melonite, calaverite and altaite which occurred at Carson Hill intergrown with free gold. A recent examination of a suite of specimens from Angels Camp and Melones shows that some of the altered rocks consist of sericite with embedded grains of calcium-magnesium-iron carbonates and pyrite. In other places the carbonates prevail over the sericite, while in a third and very common type much of the sodium, abundant in the amphibolite, has been retained as albite in the altered rock. Large grains of carbonates are separated by a granular mass of quartz, albite, pyrite and sericite.

At the Melones mine a specimen was found to contain sharply defined octahedrons of magnetite, embedded in the usual sericite felt of the altered amphibolite; this is, I believe, the first instance recorded of the occurrence of a magnetite as a product of rock alteration in a California gold quartz vein. Tourmaline has not thus far been found.

The California veins are, as well known, of early Cretaceous or late Jurassic age, and were formed at a considerable depth below the surface. The remarkable similarity of the rock alteration at the Mother Lode mines to that at Kalgoorlie shows conclusively a deposition of the gold-bearing veins from solutions practically identical in their general composition.

ON THE ORIGIN AND RELATIONS OF THE NICKEL AND COPPER DEPOSITS OF SUDBURY, ONTARIO, CANADA.[1]

ALFRED ERNEST BARLOW.

SECOND PAPER.

COMPOSITION OF THE ORE-BODIES.

The ore bodies with which the nickel and copper are immediately associated consist essentially of pyrrhotite (mostly Fe_8S_9), which is the predominant constituent, and chalcopyrite ($CuFeS_2$) usually in much smaller amounts. It has been conclusively proved by means of the magnetic experiments carried on by Brown,[2] Dickson[3] and the writer,[4] that the nickel present in these ore bodies is not, as so many have supposed, an essential constituent of the pyrrhotite, isomorphously replacing an equivalent amount of the iron, but is mainly present as a distinct and magnetically separable nickel-iron-sulphide known as pentlandite ($(Ni + Fe)S$).

This pentlandite is usually very finely and uniformly distributed throughout the whole mass, although in certain mines, as the Creighton, Copper Cliff, Evans, and, very noticeably, the Worthington mine, it occurs in spots and patches, often as much as half an inch to an inch or even more in diameter of fairly pure material. The relative abundance of this nickel-iron-sulphide determines the richness, or otherwise, of the containing deposit. Pyrite also occasionally contributes to the formation of these deposits, and much of it is nickeliferous. Present opinion varies somewhat in regard to the form in which the nickel is present in this compound, Dr. Walker's[5] researches tending to prove

[1] Published by permission of the Director of the Geological Survey of Canada.

[2] *Engineering and Mining Journal,* Vol. LVI., Dec. 2, 1892, p. 566.

[3] *Trans. Amer. Inst. Min. Eng.,* Vol. XXXIV,, 1903, pp. 14–23.

[4] Ann. Rep. Geol. Surv. Can., Vol. XIV., 1904, Part H, pp. 136–141.

[5] *Amer. Jour. Sci.,* Vol. XLVII., 3d series, April, 1894, pp. 312–314.

that this element replaces isomorphously an equivalent amount of iron in chemical combination, while others regard intermixed pentlandite as the source of the nickel. Certain other sulphides of nickel also contribute to the unusual richness of these deposits. These are relatively much less important, and many of the occurrences, where such minerals are present, are—so far as known—of no commercial importance. A varying amount of gangue, usually of the associated eruptive, but occasionally also of the older green schists, greywackes and even quartzite, is always present. The percentage of such intermixed rocky matter is sometimes unusually large, as in certain portions of the Elsie and Murray mines, where a large amount of material has been used consisting of sulphides and rock in about equal proportion; in other instances, as at the Creighton and Victoria mines, the sulphides are so pure and massive that large quantities of associated norite have to be added to the furnace charge to act as a flux. Magnetite, and certain of the silicates peculiar to the norite, usually more or less decomposed, such as hornblende, actinolite, serpentine or chlorite, are almost always present. A comparatively small amount of quartz, calcite, dolomite and, very occasionally, crystals of tourmaline, molybdenite, and apatite, are also found.

The pyrrhotite and chalcopyrite are not, as a rule, so intimately commingled as to form a homogeneous mass, but each may be described as occurring in pockets, spots, bunches or threads in the other. The chalcopyrite is not so closely intermixed with the pyrrhotite, but tends to isolate itself in patches or spots, usually inclosing, but occasionally inclosed by, the pyrrhotite. It is sometimes possible to separate considerable masses of chalcopyrite, assaying over 30 per cent. of copper or pyrrhotite, that will only show traces of that metal. In practice, however, careful examination and trial have proved that the two minerals are too intimately associated to make sorting by hand at all practicable. Although the chalcopyrite seldom occurs free from the pyrrhotite, large and massive deposits of the latter occur comparatively free from copper. The first ore shipped from the Gertrude mine was so free from copper that

it was proposed to utilize it for the production of ferro-nickel, and this deposit was purchased by the Lake Superior Power Company with that object in view. Analyses made of a large mass of the Creighton mine ore, obtained near the surface, showed the nickel to vary from 4.87 per cent. to 5.31 per cent., with 0.72 to 1.20 per cent. of copper. The prevailing intimacy of association, however, of the pyrrhotite and chalcopyrite will perhaps be better appreciated by mentioning the fact that hand-picked specimens from the Evans, Stobie and Copper Cliff mines, collected and analyzed by Mr. Browne,[1] showed the presence of from 13.86 per cent. to 15.71 per cent. of copper, with a sufficient quantity of intermixed pyrrhotite and pentlandite in the same to assay from 1.28 per cent. to 2.47 per cent. of nickel. On the other hand, selected nickel ore from Copper Cliff mine, with 8.12 per cent. nickel, contained only 0.80 per cent. of copper, while similarly picked ore from the Evans mine, containing 5.36 per cent. nickel, showed the presence of only 0.49 per cent. of copper. In certain of the deposits, as for instance at the main shaft of the Victoria mines, the nickel and copper are almost identical in quantity, assays of a large number of samples, neglecting the insoluble matter, showing the presence of 3.66 per cent. of each metal. At the Dominion, Murray and Elsie mines, the amount of nickel is usually nearly double that of the copper. Thus, Mr. George Attwood, M.E.,[2] at one time manager of the Dominion Mineral Company, under date of March 18th, 1891, stated that the "kies" or metallic portion of the Blezard mine averaged 4 per cent. of nickel and 2 per cent. of copper, this result being the average of a large number of assays, as also of the practical working of the mine. About the same date, Mr. F. R. W. Daw, then manager at the Murray mine, stated that an average of the ore smelted at this mine contained 1.5 per cent. of nickel and 0.75 per cent. of copper. Other assays of an average sample or ore show 0.9 per cent. of copper with 1.5 per cent. nickel and 46 per cent. of insoluble matter, or the equivalent of 1.66 per cent. of copper and 2.76 per cent. of nickel in the pure sulphide material.

[1] *Eng. and Min. Jour.*, December 2, 1893, Vol. LVI., p. 566.

[2] Ann. Rep. Geol. Surv. Can., Vol. V., 1890-91, Part F, p. 52.

The Gertrude and Creighton mines, especially the latter, are deposits in which the nickel is often present in the ore in the proportion of 3 or 4 : 1. In the first years of the development of the mines of the Canadian Copper Company, the copper was greatly in excess of the nickel, and assays of specimens of raw ore taken without selection from these mines showed a range in copper from 4.03 per cent. to 9.98 per cent., with an average of 6.44 per cent., while the nickel in the same specimens varied from 1.12 per cent. to 4.21 per cent., with an average of 2.38 per cent. This preponderance of the copper was maintained for some time, for an average of two samples of the blast furnace matte taken 22d February, 1889, and the 2d March of the same year showed copper 26.91 per cent. and nickel 14.14 per cent. About the same time the Dominion Mineral Company produced mattes containing from 18 to 20 per cent. of copper and 24 to 26 per cent. of nickel. At the present time, however, this condition of affairs is reversed, and two specimens of this matte analyzed by Mr. Donald Locke of this Department showed 14.53 per cent. and 14.69 per cent. of copper, with nickel 26.34 per cent. and 28.17 per cent., respectively.

The quantity of nickel in the pyrrhotite of the Sudbury district varies, usually, from 2.25 per cent. to 5.50 per cent., the lower figure being characteristic of such deposits as the Stobie, Murray and Elsie mines, while the higher is approached, and at times exceeded, by the ore of the Creighton, Victoria, Blezard, Copper Cliff and Evans mines. Small specimens are occasionally met with which contain as high as 30 per cent. nickel—as at the Worthington or Creighton mines—but such material is only obtainable by careful hand-picking. These ores contain appreciable quantities of cobalt, gold, silver, and metals of the platinum group. Cobalt is almost invariably present, but most of the assays that have been made of the ores show it to be included with the nickel. The cobalt is usually very uniform in amount, in the proportion of 1 : 40 or 50 of the nickel present. The amount of the rarer elements, such as gold, silver and platinum, is usually so small that the proportions of these can be best determined by analyses of the Bessemer or higher grade mattes.

Available analyses of this product which contain about 80 per cent. of combined nickel and copper also show from 0.10 to 0.20 oz. of gold, with an average of perhaps 0.15 oz. to the ton of 2,000 lbs.

The silver in the ore is still more variable. Locke found 2.5 oz. to the ton in the Orford Copper Company's matte and 4.87 oz. to the ton in the matte produced by the Mond Nickel Company. J. W. Bain's[1] analyses show 5.1 oz. to be present in the Orford Copper Company's matte. L. P. Silver shows that 5.30 oz. are present in each ton. The platinum is directly associated with chalcopyrite and therefore should be found in mattes which are relatively richer in copper. Locke found that the Orford matte contains 0.44 oz. per ton of metals of the platinum group, while the Mond Nickel Company's matte contains 0.4 oz. per ton of these same metals.

MODE OF OCCURRENCE.

Most geologists who have examined these deposits in detail are agreed that they are not true fissure veins, and although at times certain sloping surfaces are obtained which seem to have a uniform direction and limit the distribution of ore in their direction, yet it seems certain that there are no regular walls, in the miner's sense of the term, and at both sides of the deposits the inclosing rock is impregnated, more or less, with pyritous matter. Although mining is thus rendered somewhat difficult and uncertain on account of the absence of the walls, and irregularity in the distribution of the ore—so that there is very little opportunity of knowing in what direction to drive the levels—this uncertainty is usually more than compensated by the extent and massiveness of the deposits when found.

The ore bodies are of irregular, oval or pod-shaped outline, and all agree in having their longer axis correspond very closely with the direction of the foliation of the inclosing rocks.

There are three main types of these ore deposits:

1. Those which occur at the outer edge of an immense intrusive sheet of hypersthene gabbro or norite. Under this di-

[1] Ann. Rep. Bur. Mines, Ont., 1900, p. 218.

vision are included the Gertrude, Creighton, North Star, Tam O'Shanter, Lady Violet, Elsie, Murray, Cameron, Little Stobie, Mount Nickel, Blezard, Shepherd, Kirkwood and Cryderman mines.

2. Those which are developed in connection with offsets or dike-like forms of the norite extending outward from the main mass, and which are intruded into the older rocks almost at right angles to the planes of foliation and bedding. This division would embrace such mines as the Victoria, Clarabelle (No. 6), No. 4, Lady Macdonald (No. 5) and No. 2, and the extensions of No. 2 mines of the Canadian Copper Company. Many of the "prospects" in the townships of Bowell and Fry—on what is usually referred to as the North Nickel Range—are also connected with an irregular, dike-like offset which extends from the main mass in a northwesterly direction for nearly six miles.

3. Those which are associated with smaller and at present completely isolated bodies of norite. These separate masses of the nickel-bearing eruptive are so closely identical in mineralogical composition, structure and behavior with the parent eruptive that it seems reasonable to suppose that they are connected with it in some way at a distance below the surface.

The original Copper Cliff, No. 1, and its extensions, Evans, Frood (No. 3) and Stobie Mines, are all examples of this last mentioned class.

The first mentioned division of deposits are all situated at the immediate contact between this huge mass and the older rocks into which it is intruded. The intrusive nature of this contact is almost everywhere well shown, the impregnation of the older green schists consisting, for the most part, of small, dike-like forms of sulphide material injected along the planes of schistosity. On the other side, the line of separation between the ore-body and the norite is even more uncertain, the sulphide material gradually fading out until it is represented by only occasional disseminations. To the northwest, this basic rock shows a gradual differentiation or passage into the peculiar and characteristic type of gneissic granite usually referred to as "micropegmatite." On the Northern Nickel Range this condition of

affairs is reversed, and we find the deposits at the northwestern margin of the norite, while its differentiate—the micropegmatite—lies to the southeast.

The Worthington and the Vermilion Mines are the only deposits which have been worked, having no visible connection with this main mass of norite. The Worthington Mine occurs on a narrow neck of actinolite-diorite which is, without doubt, the altered representative of an older norite. To the southwest and east this norite is directly connected with a much larger mass of basic eruptive material. As far as can be learned, no large deposit of ore was encountered at the Vermilion Mine and the small amount of norite found resembles very closely the decomposed variety of the older type of this rock.

Rounded hills of gossan, indicating the presence of the more or less pure and unaltered ore beneath, extend with almost unbroken continuity for miles along the line of junction, while by far the larger portions of the offsets and isolated masses with which the ore-bodies are associated are also of a prevailing brownish color, due to the decomposition of abundantly disseminated sulphides. This gossan has resulted, as usual, from the alteration of the pyrrhotite and chalcopyrite and the formation of hydrous oxide of iron which gives a prevailing brownish color to the upper portions of the deposits. The covering of iron oxide is sometimes as much as six feet in depth, although usually it is only two or three feet, gradually merging into the unaltered ore beneath.

The depth to which the gossan extends depends largely, of course, on the length of time the deposits have been uncovered, and thus exposed to processes of weathering. Some, from which the green forest and overlying soil have but lately been removed, show little or no iron oxide, while others, like the Murray Mine, which have been exposed for years to the action of the weather, exhibit an extensive covering of this characteristic decomposition product. From the Elsie Mine in a northeasterly direction, past the Murray Mine as far as the boundary between McKim and Blezard townships, a considerable belt of rock occurs at the immediate margin of the norite, so heavily charged with sul-

phides, that its weathered outcrop at the surface is covered with gossan. At the old Copper Cliff Mine, as well as at the Creighton Mine, the overlying gossan is very widespread and deeply impressive.

In many cases, these ore-bodies show a brecciated character, large angular or partially rounded blocks of almost barren rock being mingled with the ore. Some of these "horses," as they have been called, are made up of the material derived from the wall rock, against which the pyritous matter cooled. Their presence, in this connection, is no doubt due to the shattering of the invaded formation at their contact with the plutonic magma. In fact, they form an illustration, on a small scale, of the phenomena of "overhead stoping" so fully described and explained by Dr. R. A. Daly.[1] In other instances, however, this comparatively barren material is of the norite, but such inclusions are seldom sharply defined from the sulphides, exposures showing a gradual transition from one to the other, while the blocks themselves are generally more or less plentifully impregnated with the prevailing sulphides.

No great depth has yet been reached by the workings of any of the mines of the marginal type of deposits; the deepest of the shafts is at the Blezard Mine which has only reached a depth of 172 feet, while those of the Murray and Gertrude Mines are 160 feet and 120 feet deep respectively. On the other hand, the diamond drilling undertaken at the Creighton Mine is stated to have proved the existence of this phenomenally large body of nickel ore to a depth of at least 400 feet. This wonderful deposit of pyrrhotite has been worked mainly as a large open pit measuring 150 by 200 feet and extending to a depth of 62 feet. All of these deposits on the southern border dip to the north and northwest at an angle varying from 30° to 70°.

Of the mines developed along the offsets, the two most important are the Victoria Mine and the No. 2 mine of the Canadian Copper Co. at Copper Cliff. The Victoria Mine, of the Mond Nickel Company, with extensive levels and stopes has reached a depth of about 800 feet. The No. 2 mine has afforded

[1] *Amer. Jour. Sci.*, Vol. XVI., 1903, p. 108.

a large amount of ore, being worked, for the most part, as a large open pit measuring about 250 feet in length by 100 to 150 feet in width and with a depth of 217 feet.

The original and famous Copper Cliff Mine has often been referred to as a chimney of ore, averaging in width from 50 to 100 feet in the cross section through the shaft, while at right angles to this direction, it varies from 30 to 210 feet. The first or old shaft, now in large part abandoned except for pumping purposes, was sunk to a depth of over 500 feet in an incline of 40°, while shaft No. 2, or the new shaft to take its place, starts from the third level at a distance of 150 feet from the surface, and continues at an angle of 77° 30′ or approximately parallel to the ore-body to the 14th level (depth 1,058 feet).

The ore-body of the Stobie Mine developed in connection with a small isolated mass of norite has an inclination of 65° and, although the workings have only reached a vertical depth of 250 feet, it has yielded a very large amount of ore (400,000 tons).

UNDERGROUND WATER INVESTIGATIONS IN THE UNITED STATES.[1]

MYRON L. FULLER.

INTRODUCTION.

So abundantly watered were the first settled parts of this country, with the exception of the Spanish settlements in New Mexico, and in southern California and adjacent regions, that for two centuries and a half problems of water supply had seldom to be considered. But with the tide of westward immigration into the arid lands and the growing congestion in the East the water question became more acute. The streams and shallow open wells no longer furnished sufficient water for the increasing demands made upon them for both public and industrial purposes, while owing to the greater frequency of pollution, new and safer supplies for domestic purposes were urgently demanded. From surface streams attention was diverted to the underground waters, and the number of deep wells multiplied rapidly as their value as sources of public supply and for manufacturing purposes became better known. In late years such wells have also come to be of great importance to the grazing industry and even in the irrigation of many of the desert basins of the arid West.

DEVELOPMENT OF HYDROLOGIC INVESTIGATIONS.

Early Studies.—As the demand for underground waters increased not only were scientists attracted to the problems of their occurrence, but their importance was recognized by the various state organizations and even by the federal government. Considerable boring had already been done in the "fifties" and the geologic and agricultural reports of Mississippi and other states contain references to the methods of drilling or to the occurrence of underground waters. In 1883 the Geological Survey of Wis-

[1] Published by permission of the Director of the United States Geological Survey.

consin published a very valuable report [1] on artesian waters, which had already become of great importance in that State. Iowa, in 1897, issued a report[2] on artesian waters, which up to the present time has not been surpassed by any report on a like area. New Jersey for a number of years has discussed annually [3] the artesian developments during the year. Georgia in 1898 issued a report [4] similar to that of Iowa, though less elaborate, while in the last five years Louisiana,[5] Michigan,[6] Washington,[7] Nebraska,[8] North Dakota,[9] Texas,[10] and Mississippi,[11] have all published more or less detailed papers on underground waters. In addition to the reports on general subterranean water resources, Kansas,[12] Missouri,[13] Illinois,[14] and Indiana,[15] have is-

[1] Chamberlin, T. C., "Artesian Wells," Wis. Geol. Survey, 1873–1879, Vol. 1, 1883, pp. 689–701.

[2] Norton, W. H., "Artesian Wells of Iowa," Iowa Geol. Survey, Vol. 6, 1897.

[3] Annual reports, New Jersey Geol. Survey.

[4] McCallie, S. W., "Preliminary Report on the Artesian Well System of Georgia," Bull. No. 7, Geol. Survey of Georgia, 1898, 214 pp.

[5] Harris, G. D., and Pacheco, J., "Subterranean Waters of Louisiana," Geol. Survey of Louisiana, Report of 1902, pp. 195–252. Harris, G. D., and Veatch, A. C., aned others, "Report on the Underground Waters of Louisiana," Geol. Survey of Louisiana, Bull. No. 1, 1905.

[6] Lane, A. C., and others, various reports on wells and underground waters, Reports of State Board of Geological Survey of Michigaen for 1903 and for 1904.

[7] Vol. 1, Washington Geol. Survey.

[8] Vol. 1, Nebraska Geol. Survey.

[9] Bulletin of State Univ. and School of Mines of North Dakota, Vol. 1, No. 1, 1902.

[10] Reports of Geol. Survey of Texas; bulletins of Texas Univ. Mineral Survey.

[11] Logan, W. N., and Perkins, W. R., "Underground Waters of Mississippi," Bull. No. 89, Miss. Agr. Exp. Sta., 1905, 112 pp.

[12] Bailey, E. H. S., "Special Report on Mineral Waters," Univ. Geol. Survey of Kansas, Vol. 7, 1902.

[13] Schweitzer, Paul, "Mineral Waters of Missouri, Missouri Geol. Survey, Vol. 3, 1892.

[14] Palmer, A. W., "Chemical Survey of the Waters of Illinois, 1897–1903, Univ. of Illinois, 1903.

[15] Blatchley, W. S., "Mineral Waters of Indiana," 26th Ann. Rept. of Dept. of Geol. and Nat. Resources of Indiana, 1903, pp. 11–158. Hessler, Robt., "Medicinal Properties and Uses of Indiana Mineral Waters," ibid., pp. 159–226.

sued important reports on mineral waters from wells and springs and their therapeutic uses.

Government Investigations.—The federal government, however, especially in the last few years, has been the leader in underground water investigations. In one of the earliest reports of the United States Geological Survey is found a discussion [1] on the requisite and qualifying conditions of artesian flows which still remains a standard. In 1892 there was published as a Senate Document an elaborate report [2] on the results of work conducted under the direction of the Secretary of Agriculture on artesian waters, underflow, and irrigation. Since 1894, when a clause providing for the investigation of underground currents and deep wells was introduced into the appropriation bill, the Geological Survey has given systematic attention to underground water problems.

Under this authority the Survey, in addition to making studies of streams, reservoirs, and irrigation systems, collected and published more or less information relating to artesian and other deep wells, the reports including discussions of the underground water resources of the Arkansas Valley, the Edwards Plateau, the Dakotas, Nebraska, Illinois, Indiana, Ohio, and the States of the Atlantic coast from New York to Georgia.

As underground water problems increased in importance it became necessary, in order to segregate this work, for which purpose a new division known as the Division of Hydrology was organized, for the sole purpose of investigating underground waters.

Nature of Hydrologic Work.—The term hydrology has been applied in the past to the study of waters of any kind, either surface or underground, but the Geological Survey limits its use to subterranean waters, restricting the term hydrography to the study of surface waters. The terms in fact are used analogously to geography and geology—to apply respectively to the superficial and to the underground or fundamental features. Hydrology as

[1] Chamberlain, T. C., "Requisite and Qualifying Conditions of Artesian Wells," 5th Annual Rept. U. S. Geol. Survey, 1885, pp. 125–173.

[2] Senate Exec. Doc., 52d Cong., 1st Sess., Vol. 4, Irrigation, 1892.

thus used is synonymous with geohydrology—the science of earth waters.

The hydrologic work of both the State surveys and of the general government consists in the investigation of the occurrence of underground waters and has no relation to the gaging of streams or allied studies of surface waters. All of those engaged in the work are geologists, and, with the exception of a few technical studies, the investigations are from a geologic standpoint, in fact their object is the determination of the geologic relations of underground waters. But although the studies, owing to the fact that the occurrence of the waters must always be governed by geology, are mainly geological, the hydrologist does not stop there, but after unraveling the geology proceeds to take up the questions of hydraulics, of chemistry, and the economic phases of the problem. In fact, although the hydrologist must do the whole work of the geologist, this is but the beginning of the investigation.

CHARACTER OF HYDROLOGIC PROBLEMS.

GENERAL INVESTIGATIONS.

Nature of the Work.—By general investigations are meant those which have for their object the study of the general underground water resources of a region. Such investigations include primarily a study of the geology since it is upon this that the occurrence, quantity, and quality, depends. Topography comes in for a large share of attention, controlling as it does the hydraulic conditions, especially the head of the water. In geology, not only are areal examinations made, but careful attention is given to well records. In fact, in some reginos where ordinary geologic methods fail entirely it is possible by means of such records to work out the details of underground stratigraphy and structure with considerable accuracy. In topographic work level-lines are often run for the purpose of delimiting areas of flow, determining the geologic structure, and solving other problems dependent upon elevation.

Following or accompanying the geologic investigations, studies

of the more purely water features are undertaken. These include the location and measurement of depths of wells, the determination of the head, quantity and temperature of the water, chemical examination of the composition of the supplies, the location, elevation, character of the catchment areas, and the investigation of many minor probems. Emphasis is laid on the economic features, and it is the aim to determine and present to the people of each district investigated statements as to underground water prospects and recommendations as to sources of new or better supplies.

Preliminary Steps.—The geologist on taking up a new problem examines the published literature relating to the field. The hydrologist does this and goes a step farther. By means of printed circulars addressed to postmasters, county surveyors, engineers, and other officials, very full data is obtained in regard to the general water conditions, the source of domestic, manufacturing, and public supplies, together with the names of well and spring owners and of drillers. To the names thus obtained special blanks, relating to a single well or a single spring, are sent. When returned, these furnish a very good basis for drawing up plans for field work, inasmuch as from them are obtained many valuable details as to the location of important wells and springs, the depth and character of water, the source and adequacy of public supplies, etc.

Field Work.—In the field, geology and underground waters are usually studied together. Special attention is given to the stratigraphy and structure governing the occurrence of the waters, both surface and well data being, as previously indicated, utilized. In some instances, where fossils have given the only clue to the stratigraphy, paleontologists have taken a leading part in the work. Physiographic studies are often made as they afford a guide to topographic correlations and are of much assistance in problems relating to the catchment areas and head of the waters. The texture and mineral composition of the formations encountered are also carefully examined, for upon the former depends the porosity and water-bearing capacity, and upon the latter

the composition of the supplies. In the harder and more compact rocks special attention is given to bedding planes and joints, for in such materials these govern to a large extent the occurrence of the water.

The points covered in the water studies have already been enumerated. In collecting the data it has been found more satisfactory and economical to employ temporary assistants, which are often secured on the ground, leaving the geologic and broader hydrologic problems, especially of correlation, to the more experienced and expensive hydrologists. Special attention is given to the quantity of the water (tables for its computation being supplied); to the temperature, which has proven a valuable check on statements as to depth, and to the composition of the waters. In the study of the latter a field outfit supplied by Mr. M. O. Leighton of the Division of Hydro-Economics, United States Geological Survey is often used. By means of this outfit the hardness, normal and acid carbonates, calcium, total sulphates, chlorine, iron, color, and turbidity—or practically all the features of significance in a water intended for industrial or boiler purposes—can be determined in half an hour.[1] This examination may be made either in the field or samples may be collected and the analyses made at camp or hotel.

Results of the Work.—To enumerate the localities in which more or less extensive investigations of a general nature have been conducted would be to give a list of nearly every state in the Union. Among the regions in which more important investigations have been carried on are the Coastal Plain of California, the portion of the Great Plains underlain by the Dakota Sandstone, the Texas Black Prairies, the Mississippi embayment region, and the Atlantic Coastal Plain.

SPECIAL INVESTIGATIONS.

Collection of Well Samples.—In addition to collecting records in the field the United States and certain State surveys have for some years attempted to obtain samples of the rocks penetrated by

[1] For full description see "Field Assay of Water," by M. O. Leighton, Water Sup. and Irr. Paper No. 151, 1905, 77 pp.

deep borings. The former, in fact, now has in operation a very effective system for collecting and preserving such samples, which at the end of a little less than two year's work, has over 1,000 sets of samples, including over 15,000 specimens. At the inauguration of the system the objects of this work and the advantages to be expected were presented to all drillers whose addresses could be obtained through directories, enginering publications, advertisements, newspaper clippings, or from geologists and others, and their cooperation invited. To those responding special note books containing simple definitions of geologic terms and rocks, directions for saving samples, and space for recording records, were furnished, together with supplies of small canvas bags provided with printed franks by means of which the samples could be forwarded through the mails free of charge. On receipt of the samples they are transferred to small bottles and examined, and after records have been compiled are stored in compact filing cases where they are always instantly available for inspection to geologists and visiting drillers and well owners. A report giving the results of the work for the year is issued annually.[1]

Measurement of Underflow.—One of the most interesting of the special problems, and one which has proven of great importance in the reclamation work in the West is the measurement of velocity and volume of the underflow. Until the last few years most estimates of underflow were little more than guesses. In a few cases what is known as the chlorine method, consisting in the insertion of common salt into the groundwater body and the collection of water samples at stated intervals from surrounding wells, etc., was employed. These samples were afterward analyzed and the rate of movement determined from the time required for the salt to penetrate to the wells. A marked improvement on this method is found in the self recording electrical apparatus invented by Professor Slichter.[2] In using this an electro-

[1] Fuller, M. L., Lines, E. F., and Veatch, A. C., "Record of Deep Well Drilling for 1904," Bull. No. 264, U. S. Geol. Survey, 1905, 106 pp.

[2] Description of underflow meter used in measuring the velocity and direction of underground water. Water Sup. and Irr. Paper No. 110, U. S. Geol. Survey, 1905, pp. 17–31.

lyte, usually salt or sal ammoniac, is placed in the upstream well from which it passes into the groundwater. When it reaches the down-stream well its presence is immediately recorded through electric connections on a revolving drum which operates by clock work. It does away with the necessity of keeping an observer constantly at the well and saves the trouble of making analyses. In fact its use has revolutionized the methods of measuring underflow in many public supply and irrigation investigations.

Principles of Occurrence of Underground Waters.—Studies of the principles of occurrence of underground waters form an important part of hydrologic investigations, especially those of the National Survey. The general principles applicable to waters in bedded sedimentary rocks have long been known and are discussed in every text-book. Later work, however, has shown the existence of so many modifications that hardly one of the supposed requisites is now considered essential.

Numerous flows from crystalline rocks are now known in Maine[1] and elsewhere, while flows from horizontal beds and from beds without impervious cover,[2] are not uncommon. All these are under investigation, and "type studies" are being made of the occurrence of water in the principal classes of deposits, especially in crystalline rocks, limestones, clays, and drift deposits. The work has been found to yield an intimate knowledge of the actual conditions which often leads to conclusions widely at variance with assumed theoretical conditions. The work has some very practical economic bearings, which have been of much value in furnishing a basis for the direction of drilling operations.

Pollution Experiments.—A number of experiments have been undertaken by both the National and certain State surveys to determine the possibility of the pollution of wells through the introduction of sewage into borings leading to underground streams in limestone. In several instances salt has been inserted

[1] Smith, G. O., "Water Resources of the Portsmouth-York Region," New Hampshire and Maine, Water Sup. and Irr. Paper No. 145, U. S. Geol. Survey, 1905, pp. 120–128.

[2] Fuller, M. L., "Two Unusual Types of Artesian Flow," Water Sup. and Irr. Paper No. 145, U. S. Geol. Survey, 1905, pp. 40–45.

into wells in large quantities and the effect on surrounding wells noted. At Quitman, Georgia, it was shown[1] that the introduction of sewage would have resulted in the contamination of every well in town. At Fort Oglethorpe in Chickamauga Park, Georgia, it was proven that the Fort well had underground connection with a nearby sink, through which polluting matter had obtained access to it.

Drainage Problems.—Allied to the preceding is the problem of draining by means of wells those wet lands and lakes where the waters are held above the normal water level by local clayey beds. The question whether or not the drainage through wells will result in a pollution of the groundwater used for domestic or public supplies is first determined, and if it is found no harm will follow, the character of the underlying materials, their porosity, and the head of their contained waters, are investigated. It has been found that such drainage may be successfully practiced in many places in the regions of glacial deposits, especially in Michigan, and it is beginning to be successfully used in the excessively flat lands of eastern Arkansas.

Methods of Sinking Wells.—It has been found that many drillers purchase outfits without properly considering their adaptability to the conditions under which the work must be done. Laborious and costly methods are employed where others much cheaper and more effective could be used if the driller had known of them. One of the latest of the special studies has been the investigation of the various well drilling outfits and their applicability in different kinds of rocks. The treatment of quicksand, handling of casing, measurement of deflection, methods of fishing, and the numerous other problems encountered by the driller have also been studied and the whole compiled in a technical report on well drilling methods and appliances,[3] which

[1] McCallie, S. W., Experiment relating to problems of well contamination at Quitman, Ga., Water Sup. and Irr. Paper No. 110, U. S. Geol. Survey, 1905, pp. 45–54.

[2] Horton, R. E., "Drainage of Ponds into Drilled Wells," Water Sup. and Irr. Paper No. 145, U. S. Geol. Survey, 1905, pp. 30–39.

[3] Bowman, Isaiah, Report in process of publication as a Water Supply and Irrigation Paper.

will afford the driller information as to the outfit best fitted for any given class of work, descriptions of the methods of operation, data as to the cost, etc.

Preparations of Bibliographies.—The need of bibliographies is especially pressing in hydrologic work owing to the newness of the science in its present development and the scattering character of the references. The United States Gological Survey has for some time been engaged upon the preparation of a series of bibliographies on the subject. One of these, covering the publications of the Survey, has already been issued, while another covering practically all scientific literature published in the United States in 1905, is in press. Considerable progress has also been made on a general bibliography of underground waters.

Mineral Waters.—Several states, including Kansas, Missouri, Illinois, and Indiana, and the United States Geological Survey have published descriptive or statistical reports relating to mineral waters. Many analyses have been published,[1] statistics presented,[2] and waters described.[3]

Miscellaneous Problems.—Besides the more important problems mentioned above numerous others have been under investigation by the State or National surveys, a bare enumeration of which will be sufficient. These include: (1) The location of water wells for public or private supplies, (2) the scientific direction of well-drilling operation, (3) the prevention of borings in unfavorable localities, (4) the identification of horizons and interpretation of records for drillers, (5) the furnishing of

[1] Peale, A. C., Lists and analyses of the mineral springs of the United States, Bull 32, U. S. Geol. Survey, 1886, 235 pp. Gooch, F. A., and Whitfield, J. E., Analyses of waters of the Yellowstone National Park, with an account of the methods of analysis employed, Bull. 47, U. S. Geol. Survey, 1888, 84 pp.

[2] Fuller, M. L., Notes on springs, wells, and general water resources of certain eastern and central states, Water Sup. and Irr. Paper No. 102, 1904, pp. 21–512. Peale, A. C., Mineral waters. Reports on mineral resources of the United States, 1893 to 1904, 16th and 21st Ann. Repts. U. S. Geol. Survey.

[3] McGee, W J, The potable waters of eastern United States, 14th Ann. Rept., pt. 2, pp. 1–47. Peale, A. C., Natural mineral waters of the United States, 14th Ann. Rept., pt. 2, pp. 48–88.

estimates of cost of well drilling to government and private parties, (6) the designation of spring or well supplies for special purposes, including the growth of water cress, use for fish hatcheries, use for boiler supplies, etc., (7) the prevention of freezing in "blowing wells," (8) the prevention of law suits by explaining groundwater conditions, (9) the enactment of laws for regulating the use of water, (10) the obtaining of more sensible legal decisions, (11) the furnishing of plans and recommendations to officials of foreign bureaus of hydrology, (12) the origin of peculiar mineral waters, (13) the change in composition of water in wells, (14) the uses of well and spring waters, (15) the measurement of head and flow of wells, (16) the cause of decrease or failure of wells, (17) the nature and cause of fluctuation of wells, including tidal and barometric changes, etc.

PROBLEMS FOR FUTURE INVESTIGATION.

The problems calling for investigation spring up far more rapidly than work can be conducted. Each field season develops new lines needing study, and the hydrologist who does not see enough untouched problems ahead to require his energies for years to come is dull indeed. But not only do new problems call for investigation, but the solutions of certain old ones must be completed while others must be re-solved. A few of the lines along which work is needed may be mentioned.

Sources of Underground Waters.—The question of the source of underground waters is one upon which many different views are held. That rain water is the chief source all will admit, and some go so far as to claim that it is practically the only source. Others, however, believe that magmatic waters are of wide distribution and of great importance. Again, sea waters included in the sediments when originally deposited are thought by some to be the principal source of the saline waters in certain rocks, especially in oil-bearing series, while still others believe that these waters are of meteoric origin and have derived their mineral ingredients through solution. All these questions, it is

believed, may be solved by careful detailed work and the field is a promising one for future investigations.

Depth of Penetration of Water.—Here again there are considerable differences in belief. Hoskins[1] has shown and Van Hise[2] emphasized the practical limitation of fracture zones to depths less than 10,000 meters. Because such fractures can occur many have assumed that they commonly exist and that water may freely penetrate to this depth. Others urge, however, that our deep borings and deepest mines show that circulation actually extends in most instances to but a small part of this depth, being, in fact, usually confined to the upper 2,000 feet in most rocks. Much evidence is available, which if carefully collected, as it doubtless will be at some future day, will clear up this disputed question.

Question of Saturation.—Closely allied to the question of depth of penetration is that of the problem of the saturation. In most types of fragmental rocks the water occurs in the pores, filling them to saturation wherever they are below the water level, and it has often been assumed that similar conditions exist in other rocks and that all pores are occupied by water. Recent studies of well records and samples, however, show that this is far from being true. Few of the crystalline rocks, for instance, hold anything like their full capacity of water. Many mines in both sedimentary and crystalline rocks are dry and dusty even when far below the water level, open and porous sandstones which contain no water at all have been recognized in deep wells, while clays underlying the ground water are often incoherent and powdery. Estimates of the ground-water in the earth have varied many hundred per cent. because of the different initial assumptions made in the computations. That this is so is due to the absence of sufficient observations. Here again the field is one which will yield fruitful results to the future investigator.

Nature of Circulation.—This is intimately related to the two

[1] Hoskins, L. M., Flow and fracture of rocks as related to structure, 16th Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, pp. 843–872.

[2] Van Hise, C. R., Principles of North American pre-Cambrian geology, 16th Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, pp. 581–844.

preceding problems. Briefly it may be said that opinion is divided as to whether the chief circulation is through bedding planes, joints, and similar openings, or through the pores of the rocks themselves. Abundant data from mines and wells is available which will go far towards settling the question when it is seriously taken up.

Other unsolved problems of circulation are the exact parts played by gravity, by differential temperature, by gaseous pressure, by dynamic disturbances, by exclusion by crystallization, by magmatic intrusions, by capillarity, and by many other similar agencies. There are probably few, if any, of the agencies enumerated the work of which is not susceptible of determination and which will be determined by future studies.

Lost Water.—This is one of the less important yet interesting of the unsolved problems. Many of the lower sandstones of southwestern Pennsylvania and elsewhere, although open and porous, are found by the drill to be destitute of water. That they are beyond the ordinary limit of meteoric circulation will be admitted, but as marine formations, they must have been saturated at the time of their deposition, and as they have never down to the present time been above sea or drainage level the water should, in the absence of any known means of escape, still be present. This, as has been indicated, is not the case. The problem of what has become of this water is one of the more fascinating ones left for future solution.

Source of Mineralization.—There is perhaps no line of underground water investigation about which so little is known, notwithstanding the wide interest of economic geologists and others in the problem, as the source of mineralization of the waters. In regions of recent igneous activity magmatic emanations doubtless furnish much of the mineral matter, but many strongly mineralized springs occur in regions remote from such activity and in rocks apparently incapable of furnishing the observed elements in solution. The brine springs in the Piedmont Plateau at Austell, Georgia, and the springs so highly charged with carbon dioxide at Saratoga, New York, may be cited as presenting unusually

puzzling features. But it is not only the abnormal waters which are of interest; the ordinary waters from our common rocks possess many features of composition which, though not well understood at the present time, will doubtless be worked out in the future.

Rate of Underflow.—As already indicated a method of electrical measurement is now in existence which in point of results is very satisfactory. It requires, however, the sinking of four test pipes for its operation, one on the upstream side for the insertion of the electrolite (usually a solution of salt or sal ammoniac), and three others arranged on the arc of a circle on the side towards which the water is supposed to be moving. The perfection of a device for determining the rate of movement from a single test pipe would make the determinations quicker, more convenient, and much cheaper. The principles of a mechanical device, the arms of which can be made to expand in the desired directions and to given distances, are understood, but it remains to the future to secure material of sufficient strength to withstand the strain at the joints or to accomplish the same end in other ways.

Pollution.—Probably no groundwater problem is of so great importance economically as that of pollution. Much is already known as to the manner in which it takes place, but owing to the complex groundwater currents, the part played if any by the so-called natural filtration, the efficiency of dilution, the length of the life of the germs, the rapidity of motion of the water, the concentration of pollution in definite channels, and a multitude of other similar factors, still call for investigation.

Occurrence of Groundwaters.—Only the simplest problems of occurrence have so far been mastered. Where a well defined sandy bed, like the Dakota Sandstone, occurs its depth can be estimated and the yield predicted, but in crystalline rocks, in the limestones, and in the lenticular alternations of sediments so characteristic of the Carboniferous series, predictions have in the past often been misleading and of no value. Recent work in limited areas, as in the State of Connecticut, has shown that

in the crystalline rocks it is possible by means of careful studies to determine in advance the probabilities of the success of a well within a margin of only a few per cent. error. It is believed that future investigations will show the same to be true of other types of rocks.

RÉSUMÉ.

Hydrologic work as defined by the Geological Survey is, in its main principles, strictly geological, and geologic studies constitute the foundation for most of its investigation. In fact, it has for its object the study of the geology of underground waters, and is as truly a branch of economic geology as the study of oil, gas, and the other substances universally included in the economic resources. This is now recognized by every geological survey, both national and state, and the investigation of underground waters forms a part of the work of each.

The value of the work has been universally recognized for many years and the results accomplished have been of great importance throughout great areas of our country. As yet, however, only a beginning has been made, and the work completed must be considered insignificant as compared with that left for the future.

UNDERGROUND WATER LITERATURE.

The literature relating to underground waters is very extensive. That portion relating to public supplies and general engineering will be found mainly in the various volumes of the engineering magazines, such as the *Engineering News* and the *Engineering Record*. Most of the mining magazines publish more or less numerous references to underground waters as related to the problems of ore deposition, concentration, and to mining. The reports of the many state surveys contain discussions of the underground water resources of local areas. These can often be had on application to the state geologists. The greater number of general reports, however, and practically all reports on special problems have been issued by the United States Geological Survey. This Survey has also published a bibliographic

review and index of all its hydrologic publications,[1] which will be of much assistance in looking up underground water literature, as will also its general bibliography of all literature for the year 1905.[2]

[1] Bibliographic review and index of papers relating to underground waters published by the United States Geological Survey, 1879–1904, Water Sup. and Irr. Paper No. 120, 1905.

[2] Bibliographic review and index of underground water literature published in the United States in 1905, Water Sup. and Irr. Paper No. 163, U. S. Geol. Survey, 1906.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, South Bethlehem, Penna. The full name of the author should be attached to all communications.

WHAT SHOULD APPEAR IN THE REPORT OF A STATE GEOLOGIST?

Sir: Probably the chief function of a state geological survey should be to bring before the public the natural resources of the commonwealth, to furnish information regarding the ores, minerals, clays, building stone, coal, underground waters and other geological resources of economic importance. The investigation of these subjects necessitates a detailed and careful study of the stratigraphy and the mapping of the different geological formations. All the State surveys have endeavored to supply information along the lines above specified and the reports deal in greater or less detail with the geology and economic deposits of the regions treated. The geological surveys of the different states might be of more service to the public schools than they are at present. If they would publish reports or bulletins on the physical geography and geology either of certain selected districts or of the state as a whole and with special reference to their use for instruction in the schools, they would assist the teaching of those subjects and interest the pupil in the natural features of his own neighborhood. The reports on Physical Geography and Glacial Geology, published by the New Jersey Geological Survey, are excellent examples of what may be done in this direction, though they were perhaps not intended primarily for this purpose.

In looking over the volumes issued by the various state surveys, especially those published during the past ten or fifteen years, the very marked predominance of economic subjects is at once apparent. While the strictly scientific problems, those not having a direct bearing on the development of the natural resources, have not been neglected their study has been made subordinate.

The value and completeness of the reports have of course varied considerably. In some instances the amount appropriated for the geological survey has been entirely inadequate and the work could not be carried out as it would be were ample funds available. Then too in comparing the reports made by the different State surveys on a particular subject, as clay for example, the importance, extent, variety and development of the deposits have determined somewhat the character and fullness of the treatment. In selecting certain reports as worthy of commendation the writer may fail to mention some of equal excellence which have not come to his notice.

Clays and clay industries: reports of the New Jersey, Iowa, Maryland, Ohio, Alabama and Missouri geological surveys.

Cement: two recent reports (1904) of the Geological Survey of Ohio, also those of Alabama and Iowa.

Coal: reports of the Iowa, Pennsylvania, Maryland, Ohio, and Kansas geological surveys.

Building stone: reports of the Maryland, Wisconsin and Arkansas geological surveys.

Gypsum: reports of the Michigan and Kansas geological surveys.

Lead and zinc: reports of the Missouri, Wisconsin and Iowa geological surveys.

Petroleum and natural gas: Geological Survey of Ohio, volume VI.

Also the reports of the Arkansas Geological Survey on Novaculites and Manganese.

The publications enumerated above are contributions of value made by the State geological surveys on subjects of much economic importance.

A. G. LEONARD.

DO THE GEOLOGICAL RELATIONS OF ORE DEPOSITS JUSTIFY THE RETENTION OF THE LAW OF THE APEX?

Sir:—The government of the United States has framed liberal mining laws. The provision allowing a citizen to hold a lode claim by the performance of one hundred dollars' worth of annual assessment work, in perpetuity, and to work his claim and extract ore therefrom at will from the time of location, serves to encourage prospecting, and has resulted in energetic devlopment of mining districts. The poor man may thus hold ground for several years, working on it occasionally up to and beyond the required amount, and as continuous occupation is not required, he may leave the property and work for wages at odd times, in order to earn money enough to further develop his ground. The poor prospector is further assisted by his entire immunity from tax on output. The government does not attempt to dictate to him as to the employment of labor, as does the absurd Australian prospecting law. True, the United States government does not assist the prospector in the matter of building trail, wagon-road, establishing public stamp mills, etc., as do some of the British provincial governments. In the matter of liberty to acquire, develop, and produce, however, our government aids the prospector.

The wise provisions above outlined are, nevertheless, handicapped, from the miner's standpoint, by the results of the following paragraph of the Mining Code, which went into effect May 10, 1872, and is popularly known as the "Law of the Apex."

Quot. "Sec. 2322. The locators of all mining locations heretofore made or which shall hereafter be made, on any mineral vein, lode, or ledge, situated on the public domain, their heirs and assigns, where no adverse claim exists on the tenth day of May, eighteen hundred and seventy-two, so long as they comply with the laws of the United States, and with State, Territorial, and local regulations not in conflict with the laws of the United States governing their possessory title, shall have the exclusive right of possession and enjoyment of all the surface included within the lines of their locations, and of all veins, lodes, and

ledges throughout their entire depth, the top or apex of which lies inside of such surface lines extended downward vertically, although such veins, lodes, or ledges may so far depart from a perpendicular in their course downward as to extend outside the vertical side lines of such surface locations. But their right of possession to such outside parts of such veins or ledges shall be confined to such portions thereof as lie between vertical planes drawn downward as above described, through the end lines of their locations, so continued in their own directions that such planes will intersect such exterior parts of such veins or ledges. And nothing in this section shall authorize the locator or possessor of a vein or lode which extends in its downward course beyond the vertical lines of his claim to enter upon the surface of a claim owned or possessed by another."

The words "and of all veins, lodes, and ledges throughout their entire depth, the top or apex of which lies inside of such surface lines extended downward vertically, although such veins, lodes, or ledges may so far depart from a perpendicular in their course downward as to extend outside the vertical side lines of such surface locations" are trouble-breeders. Such a piece of erroneous legislation as the above quotation represents could have originated only in the brain of an individual of limited mental capacity. How such a man could obtain a hearing in a council of law-framers is difficult to imagine. The law exhibits the ingenious sophistry which characterizes the ridiculous "theories" of irresponsible prospectors, so familiar in all western mining territory.

The Law of the Apex, this monumental blunder of experimental legislation has been so abundantly commented on by able geologists and its pernicious tendencies so thoroughly decried by all whom its treacherous meshes have entangled, that it would seem the resources of criticism are well nigh exhausted. I venture to attempt, however, to fortify the position of those who are laboring for its extinction by the exhibition of a few geological conditions which have not, to my knowledge, been previously emphasized.

The phraseology of the apex law employs the three words,

"vein," "lode" and "ledge" to cover metalliferous ore-deposits. Excepting in the case of "vein" these words have very little geological significance. The physical bodies in which payable ores occur may be for practical purposes classified into three divisions: (*a*) veins, that is, filled fissures either perpendicular or inclined to a horizontal plane, in which case the length and depth exceed the width; (*b*) stocks, either impregnated or replaced bodies of country rock, in which the horizontal dimensions may equal or largely exceed the vertical; (*c*) beds, which lie either horizontal or at an angle to the horizontal, this angle being generally small, occasionally large. In the last case, bedded deposits, the lateral extent generally greatly exceeds the vertical. Finally certain deposits afford within their limits examples of two or of all three classes of deposits, as for example when stocks of igneous rock cut replaceable beds of limestone, the whole complex being cut by metalliferous veins. Copper deposits not infrequently afford these conditions. The compilers of the apex law, as witness by the fruits of their legislation were not only entirely ignorant of such conditions, but with the temerity which is ever characteristic of folly they refused to provide for conditions which might exist beyond the small field with which they were familiar.

The law provides that the mining claim shall not exceed six hundred feet in width nor fifteen hundred feet in length, and that the territory held by the claimant shall not extend in depth beyond the end-lines, projected vertically as imaginary planes. Had it also made this provision regarding the side lines, as is the case in every other country where mining legislation exists, the public lands of the United States would have produced millions of dollars in addition to what they have produced, and other millions of dollars would have been saved to the mine owners, which have been wasted in litigation. Some states, as for example, Colorado, have rendered the law of the apex even more of a burden than it is under the federal law, by allowing only three hundred feet for the width of a mining claim.

Taking illustrations of the three cases in order, I will attempt to illustrate the incongruity of the law of the apex with actual ore occurrences.

(*a*) In Fig. 40 is illustrated a case where one set of veins has been formed earlier in the geological history of the country than another set. Mr. *A* has commenced mining on his vein which is of the earlier origin, and which dips north. Mr. *B* has located and commenced operations on his vein, a later vein, which dips south. *A* has stoped his ore down to the point *f* when he finds that it is apparently cut off and unites with the larger south-

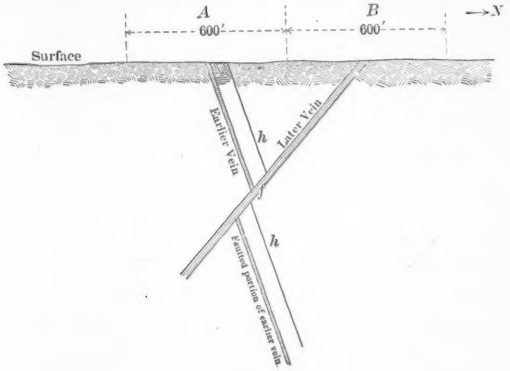

FIG. 40.

dipping vein. He knows that *B's* location is prior to his own. The law states (Sec. 2336): "Where two or more veins intersect or cross each other, priority of title shall govern, and such prior location shall be entitled to all ore or mineral contained within the space of intersection; but the subsequent location shall have the right of way through the space of intersection for the purposes of the convenient working of the mine. And where two or more veins unite, the oldest or prior location shall take the vein below the point of union, including all the space of intersection."

Not being highly versed in matters of geological science *A* suspects that his vein has united with the south-dipping vein, and as *B* has not developed it except for a few feet from surface, there is no exposure of conditions in depth beyond the work done by *A*. He can find no trace of a continuation of his vein in the foot-wall

of the large vein which he crosses. *B* meanwhile claims, under order from the court, access to *A's* workings, finds what the conditions are, and endeavors to restrain *A* from further operations. *A* asks from the court the right to follow down on the foot-wall in search for the continuation of his vein in depth. This is granted, and the small stringer *h* is found having the strike and dip of the main north-dipping vein. As his resources are being exhausted with legal expense and dead work he claims that *h* is the continuation in depth. Expert witnesses are employed, the identity of the large south-dipping vein with that which *B* has developed at the surface is established, and the claim of *A* is disallowed, as the stringer *h* is so evidently different in character from the vein which *A* has stoped to surface. *A* abandons his right to seek further, and the probability is that all the money he has won from his mining operations is eaten up by the cost of the suit which he has lost. Subsequent operations on *B's* vein develop the truth of the matter, which is that the north-dipping vein has been faulted, its lower leg thrown one hundred feet to the south, and a valuable ore-body which still exists in depth still remains for *A* to mine. Then naturally unless *A* is dead and buried, or too poor to stand the strain, there will result further legal proceedings with financial benefit to local legal talent, and further expense to the miners.

And all this, gentlemen, as a result of our brilliantly conceived law of the apex. This and innumerable analogous instances of trouble as a result of laws handed down to us by an assembly which never should have been permitted to enact legislation requiring a higher degree of intelligence to formulate than that which regulates the peace of the frontier.

Fig. 41 illustrates a section on the South African Rand where all claims are bounded by vertical lines. The main reef leader is a vein representing filled interstitial space in a bed of conglomerate, interbedded with other sedimentaries more or less auriferous. The line *aa* represents the boundary between the property of an Outcrop Company and that of a "Deep Level Company." The Outcrop Company may follow the ore down until the reef intersects this imaginary line and no farther. The Deep Level

Company may extract ore from this same reef southward from this line to its south side line, and no farther. Another set of companies, called the "Deep Deep" Companies, or second set of deeps, has been formed to exploit the main and other conformable

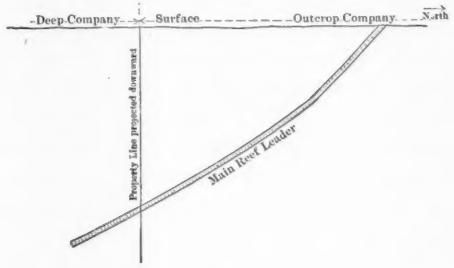

FIG. 41.

reefs still to the south of the Deep Level Companies' ground. Mr. Hennen Jennings stated in 1903 that some fifty-three level companies had been formed, fourteen of which had reached the producing stage. In the case of all of them it was necessary to sink shafts from one thousand to two thousand feet in depth in order to reach the veins, and eighty-one shafts with an aggregate of 88,405 feet of depth had been sunk for this purpose; of these fifty had intersected the reef. Beside the enormous expenditure which these shafts represented before a pound of ore could be extracted, the various financial houses estimated a further expenditure of $252,000,000 in connection with the deep levels and other projected developments.

The owners of South African mines employ the best and highest paid engineers in the world. They do not make expenditures without technical assurance that dividends will be forthcoming. Mr. Thomas Haight Leggett[1] says: "The excellent character of the mining law of the Transvaal is worthy of more than passing notice. So clear and well-defined is it, that while every square foot of ground is taken up for a length of nearly forty miles by a width of from two to three miles, lawsuits between adjoining

[1] *Trans. A. I. M. E.*, vol. 31, 1901, p. 1033.

properties are practically unknown; and as a result, the mining-law expert does not exist on the Rand."

What would have been the case if the law of the apex had existed in South Africa? Not one company of the first or second set of deeps would have been formed, and not one dollar would have been expended for the legitimate exploitation of the ore in depth excepting by the companies owning the outcrops of the veins or reefs as they are called. Numerous dikes of greenstone cut and fault the reefs, for the most part dipping much more steeply than do the reefs themselves. Some of these dikes are accompanied by auriferous veins, not payable. Under the conditions of the apex law, some energetic individual with more astuteness than integrity would have inevitably sunk on one of these veins claiming this or that as pay ore until he intersected a bona fide payable reef, which he would endeavor to lay claim to as the continuation of his vein downward, while his own "apex" might lie hundreds of feet to the south of the actual outcrop of the reef. Lawsuits would be common. Serious capital would be shy of investment under such conditions. In short, where legal conditions are actually favorable to the production of gold on the Rand, the law of the apex would be distinctly unfavorable.

(*b*) Fig. 42 is a body of porphyritic rock impregnated with iron pyrite which has within certain limits been so replaced by

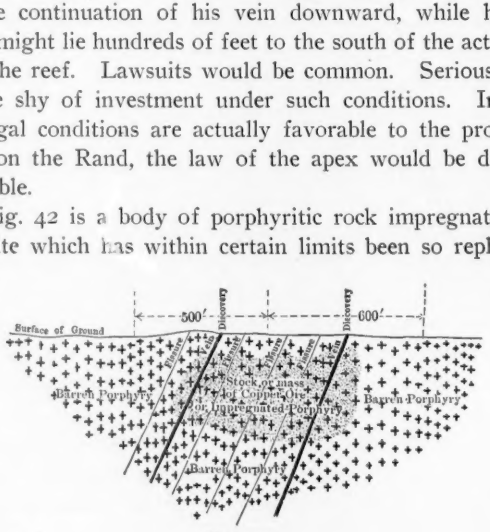

FIG. 42.

chalcocite as to represent a body of payable copper ore. Small veins, filled fissures, penetrate this body as represented. One of

these showing the decomposition products of copper ores was the visible outcrop of the copper ore body which attracted the attention of the itinerant miner. At a distance of five hundred feet away across the strike another itinerant miner locates at the same time another vein showing copper stains and both men after some desultory work manage to sell their claims to different companies who prosecute energetic development. At a depth of something over a hundred feet the great spheroidal body of payable copper ore is encountered, both fissures cutting it. This body was not visible at surface, being capped by barren siliceous or ferriferous material. What a splendid chance for a lawsuit. What visions of wealth for "Judge" Hook and "Judge" Crook and all their dreary company to make capital in proving the apex of the "vein, lode, or ledge" to be this or that fissure, of which many hundreds may penetrate the deposit. What an incentive for men who have money to invest in the establishment of large mining enterprises to pursue their operations! Tell us, Mr. Apex-law maker, would it not have been better to scan a little the mining law books of countries where such ore-bodies were mined out before you were born, before foisting upon the mining public of a great domain your ill-advised and flimsy statutes?

(*c*) Look again at the following case—Fig. 43—exhibiting a silver-lead deposit resulting from the replacement of a deformed

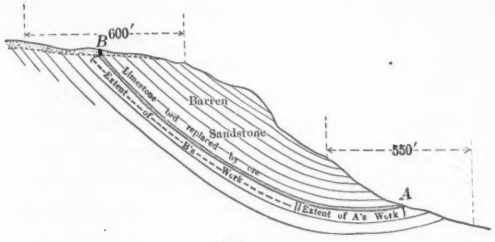

FIG. 43.

limestone bed. As shown in the sketch there are locations on both the eroded ends of this bed, or "ledge" as the law would

probably define it. The law urges that the oldest location shall take the ore in case of dispute. *A* has the oldest location in the case cited, and begins work say two years before *B* locates his claim. *B*, suspecting the true conditions, sinks to the apex of his vein, and takes out ore from the inclined bed until he meets the workings of *A*. Who owns the ore, which may have amounted in gross value to several hundred thousand dollars? Does *A*, who located the ground first, but did no work beyond keeping up his assessments, have a right to the money, or does *B* have a right to the fruits so hardly won; *B* who for several years has worked in a systematic and bona fide manner and extracted the ore from the ground?

The above cited cases are very usual geological occurrences. In every one of the instances the application of the law of the apex will cause delay, trouble and expense. A full appreciation of the significance of the law serves to turn prospective capital away from the United States, into countries where legitimate mining interests have better protection. What reason is there why an equable law should not be enacted giving the claim-holder side and end lines vertically extended is impossible to conceive. In conclusion I beg leave to submit a challenge to any man qualified to discuss the subject, asking him to advance an apology for the Law of the Apex which cannot be controverted and made ridiculous by an exhibition of actual geological occurrences, and on which an unfavorable decision will not be rendered by a corps of jurists and geologists of Germany, England, Canada, the United States and Mexico. The law of the apex is compatible neither with science nor expediency. A hindrance and frequently a barrier to the serious pursuit of mining; the laughing stock of foreign engineers and capitalists; begotten in bland self-complacent ignorance by a group of opulent mechanics, previously, and (happily for the rest of us) subsequently unknown to fame; valuable only to a certain class of pettifogging barristers and their dependents, yet this formidable spectre continues to cast its desolating shadow over a great territory eminent in mineral wealth.

C. W. PURINGTON.

DENVER, COLORADO.

HYPOTHESIS TO ACCOUNT FOR THE TRANSFORMATION OF VEGETABLE MATTER INTO THE DIFERENT GRADES OF COAL.

DISCUSSION OF PAPER BY M. R. CAMPBELL.

Sir: I may be some months late in getting into the discussion but this tardiness is due largely to my geographical position. Trusting that the subject has not yet grown cold I would like to venture a few comments on the subject of coal formation. Though I have been studying this subject in connection with a strictly economic investigation of Philippine coals for over a year now, my attention and interest was brought rapidly to a focus on reading Mr. Marius R. Campbell's admirable exposition of the subject in the first number of this journal.

It will be remembered, doubtless, that Dr. J. F. Hoffman, Berlin, as early as 1898 broached this subject in the *Zeitschrift für Physikalische Chemie.* At that time he had not as yet verified and crystallized his conclusions. In 1902 he again attacked the subject, his results appearing in the *Zeitschrift für angewandte Chemie* (Heft 33, pp. 821–831). In this article he goes very fully into both the chemical and structural facts bearing on his hypothesis. According to his hypothesis there are two principal conditions or prerequisites in the transformation of vegetable matter:

1. Spontaneous combustion (Selbstentzundung).
2. Outlet for the gaseous products through rifts, faults, etc.

He draws an analogy between the kind of slow combustion in, say, a heap of hay or other vegetable matter and the process going on in coal. He does not, if I be not mistaken, employ the term *fractional distillation,* though it would be hard to conceive this not taking place when the substance is not directly in flames. Mr. Campbell is somewhat more clear and concise in his statement of the phenomena. He does not mention direct combustion and it is not probable that any great quantity of vegetable matter has been transformed by this process. Though I do not believe spontaneous combustion to be the process by which the lower grades of coal are transformed into the higher,

still it is a very common condition of the coal deposits of the Philippines. In nearly every locality visited the coal was found to be on fire at some point or other, usually not in direct flames, but smouldering and giving off much gas.

In regard to the effect of porosity and broken condition of coal beds on this transformation process I may be permitted to contribute a few facts culled from my study of coal deposits in the Philippine Archipelago. I should state first, that I have seen nothing that does not bear out Mr. Campbell entirely in his own conclusions.

In every locality which I have visited, chiefly confined to Batan and Cebú islands, the coal deposits are intercalated in beds of more or less impervious shale or stiff fire clay and when these beds lie more or less undisturbed the coal is of a distinctly inferior grade, brown coal or sometimes a jet which has a good appearance, but is low in specific gravity and fixed carbon. On the other hand, in more or less disturbed regions as in Cebú and on the Military Reservation of Batan Island, the side nearest Mayón volcano, the coal is of a much superior grade, in fact it may be called a low grade bituminous coal and in no sense of the word lignite. It should be stated also that the volcano has had no direct effect on the deposits such as breaking by dikes and baking of the coal.

All of the deposits, which have been investigated, are of rather recent age, late Eocene and probably some of the higher horizons may prove to be Miocene.

While on this subject I wish to take a little more space in calling attention to another article in the same *Zeitschrift für angewandte Chemie* (Heft 20, p. 490, 1902) by the German chemist, E. Donath. His conclusions are radically different from those of either of the two investigators already referred to. In this article entitled, "Ueber die Bildung der Steinkohle," he postulates and endeavors to prove by numerous experiments that peat and brown coal have been formed from vegetable matter and animal matter having a totally different chemical composition from the vegetation and animal matter that gave rise to deposits of bituminous and anthracite coal.

The belief that this question will ultimately be solved by the chemist and not by the geologist, unless he be more of a chemist than a geologist, is my reason for referring to these two chemical papers.

Doubtless each hypothesis may be found in time to contribute an element to the final word on the subject.

I hope that in future articles Mr. Campbell, or someone else, will take up the relation of oil to coal deposits. Might not much of the world's petroleum be considered the product, in part at least, of this fractional distillation of vegetable deposits? The presence of oil-bearing strata closely connected with our Philippine coal deposits has led me to believe all has not yet been said on this subject.

In conclusion, I would state my gratitude to Mr. Campbell for his lucid exposition of the subject, and he may feel assured that he will have our hearty coöperation in collecting data bearing on this most interesting subject.

WARREN D. SMITH.

BUREAU OF SCIENCE,
MANILA, P. I.

REVIEWS

The Origin of Clinton Red Fossil-ore in Lookout Mountain, Alabama. By WILLIAM M. BOWRON. American Institute of Mining Engineers, Bi-monthly Bulletin, November, 1905, pp. 1245–1262.

In this contribution Mr. Bowron explains the formation of the Clinton fossil ore as resulting from the decomposition of pyrite through descending, oxidizing solutions, and implies that the process is still going on. Solutions of this kind percolating through pyrite-bearing coals and sediments of the Coal Measures, forming the more elevated portion of Lookout Mountain, have removed their ferruginous content and have carried it down and concentrated it at the Clinton horizon well toward the base of the mountain. Concentration is due primarily to the basin or synclinal structure of the mountain, and the passage of the solutions has been facilitated by axial fractures resulting from tensile strains existing in the synclinal trough.

Such an explanation, as that outlined above, of an ore deposit of the character and persistence of the Clinton fossil ore deserves more than passing notice, since it differs so completely from the prevailing ideas regarding the formation of this interesting deposit.

It is unfortunate that more of the body of the paper is not devoted to the real subject, namely, "the iron ore." It is undoubtedly true, as Mr. Bowron states, that "all deposits are at best epitomes of the surrounding conditions," and that if these be correctly interpreted, much weight must attach to deductions from a study based on such conditions, but it hardly seems necessary to give the Paleozoic and Tertiary history of eastern North America to explain an ore deposit due, as appears from the context, to purely local causes. From the inherent difficulty attached

to the study of the physical conditions which obtained during the deposition of the Clinton fossil ore, this phase of the subject may not perhaps have been treated fully enough by past writers, but it should be borne in mind that this phase is perhaps the most difficult of all to unravel. It is also wise to study intimately in a particular place the history of a particular deposit, but to avoid generalizations based on such local studies, and this is the conservative ground taken by the author; it is equally true, however, that correct interpretations made at a definite locality often serve as a key in interpreting similar deposits at widely removed points.

Objection is made in this paper to the conclusions of Hayes,[1] Newberry,[2] and Smyth[3] as to the original character of this deposit. The author of the article regards the statements of these writers "conclusive, as far as they go," but as only transferring "the question further, leaving still unsolved the problem of the *origin* of the ore." Thus he confuses the terms "source" and "origin." In no one of the writings of these advocates of original deposition is the source of supply mentioned. Obviously this could not possibly have been from the overlying beds which, according to these writers, did not exist at the time the Clinton ore was laid down. It is true, as Mr. Bowron suggests, "that its (the ore's) place of abode during previous geological time was not even hinted at," but statements on this point, except in the most general terms, must be highly speculative, and the true science of to-day, as Mr. Bowron knows, has long since outgrown the speculative stage.

On page 1249 a statement is made of the author's belief "that the ore was originally limestone, and that its replacement has been the necessary consequence of well-recognized geological laws" (are not chemical laws meant?), and that "there had always appeared to him a weak spot in the 'original deposit' idea which has furnished the following conflicting 'evidence': it was not oolitic; it was oolitic; it was of organic origin; it was

[1] Letter to Mr. J. S. Diller, dated June 10, 1896. See Bull. No. 150, U. S. Geol. Survey, p. 140.

[2] J. S. Newberry, *School of Mines Quarterly*, Vol. II., pp. 13 to 14.

[3] C. H. Smyth, Jr., *Amer. Jour. Sci.*, 3d ser., Vol. XLIII., pp. 487–496.

not of organic origin." It is not the purpose of this review to defend the exponents of the "original deposit" idea, but in justice to Mr. Smyth it should be said that a very sharp distinction is suggested in his article on the Clinton ores (page 495) between the mode of origin of the oolitic variety, which is inorganic in its nature, and that of the non-oolitic, which is a substitution product from organic fragments, but Smyth adds that the conditions which he postulates will hardly suffice for every case and that "with ferruginous material brought into sediments forming along several hundred miles of coast, iron deposits would be accumulated by various processes." There certainly is no conflicting evidence in these statements, and Bowron himself states that he has observed the oolitic and non-oolitic, the organic and inorganic character of the ore granules.

But perhaps the most interesting portion of this paper is that which relates to the mode of origin and source of the ore. Unfortunately, as has been mentioned above, this is very brief—all too brief for the magnitude and importance of the subject. The mode of derivation of the ore had better be stated in the words of the author as follows: "The Coal Measures at A (the more elevated part of the mountain, according to the diagram in the text), were gradually oxidized and the pyrite became a sulphate of iron solution which filtered through the sandstones to the axis of the mountain, where in course of time it formed a more or less concentrated solution of iron sulphate (which kind?) and the bowl XYZ was constantly fed by the enriched solutions. . . . The floors of the valleys were too high for bottom drainage from this acid earth reservoir."

In Mr. Hayes's Chattanooga folio No. 6 of the United States Geological Survey, the following generalized section down to the Clinton ore is given for the region west of Tennessee River and South Chickamauga Creek, and it holds in a general way for the Lookout Mountain district.

		Feet.
Carboniferous..	Walden sandstone (including sandy shale, with coal and fireclay beds)	1,200+
	Lookout sandstone (including sandy shale and coal beds)	400–500
	Bangor limestone	800–850
	Fort Payne chert	60–150
Devonian.....	Chattanooga black shale	10–25
Silurian.....	Rockwood shale	60
	Horizon of Clinton ore.....	

It will be seen that such iron solutions as Mr. Bowron postulates must penetrate through a considerable thickness of limestone, to say nothing of the underlying chert and shales, and must then spread out in a comparatively thin layer over the whole synclinal basin. Even the students of pseudomorphous replacement must object to this hypothesis, for it matters not in which condition the iron sulphate be held in solution, whether as ferrous sulphate ($FeSO_4$), or ferric sulphate ($Fe_2(SO_4)_3$, reaction with the Bangor limestone is bound to occur. Since oxidizing surface waters are given as the agents of conversion of the pyrite, most of the iron must be in a *higher* state of oxidation; hence the following reaction may occur: $Fe_2(SO_4)_3 + 3CaCO_3 + 3H_2O = 2Fe(OH)_3 + 3CaSO_4 + 3CO_2$, or possibly when some ferrous sulphate escapes conversion to the higher form, the following reaction might take place: $FeSO_4 + CaCO_3 = FeCO_3 + CaSO_4$. Either the limonite of the first reaction or the iron carbonate of the second would precipitate in place, or at most be carried but a very short distance into the body of the Bangor limestone. The surface of this limestone is not, so far as the reviewer is aware, an ore horizon. Bowron has himself observed "a singular instance of this impregnation in situ of an unusually high (stratigraphically speaking) limestone, which occurs 100 feet or so below the lower conglomerate" of the Coal Measures. The thickness of this limestone is stated to be two feet and its upper part has been converted into iron ore. This impregnation is a perfectly natural consequence of chemical laws and illustrates what may be expected when ferruginous solutions come in contact with limestone. This occurrence indeed falls directly into line with the arguments of the advocates of pseudomorphous replacement as a mode of origin of iron ore. The reviewer, how-

ever, must not be misunderstood as accepting this latter hypothesis, either for the Clinton ore or for all of the limestone iron ore of the Carboniferous rocks. This impregnation also illustrates the inability of such iron-bearing solutions to penetrate a limestone bed to any considerable depth without undergoing reaction with resulting precipitation of iron ore. To penetrate a limestone such as the Bangor, which is several hundred feet t[illegible], is manifestly impossible. On these grounds the ferruginous solutions from the Coal Measures could not approach to within several hundred feet of the Clinton ore horizon.

The Clinton fossil ore, moreover, is not local, even in the locality described, but is continuous more or less intermittently many miles to the northeast and southwest of Lookout Mountain and vicinity. It is also found in New York, Ohio, Kentucky, Wisconsin, and Pennsylvania, extending south into West Virginia and Virginia, besides in northern Alabama and northwestern Georgia. Any hypothesis as to the origin of the fossil phase of this ore must take this broad distribution into account. If the reviewer interprets Mr. Bowron's text correctly, the idea is presented that the deposit was formed under the conditions existing in this rather restricted field, referring to Lookout Mountain. Certainly the synclinal theory cannot be invoked for the eastern Kentucky fossil ore, or for that of New York. Hence it may be seriously questioned whether it holds for the ore in Lookout Mountain, for the character of the fossil ore in these widely scattered localities is much the same.

It is true, as Bowron suggests, that the subject needs study, and the above remarks, in part the outcome of studies made by the reviewer last summer in eastern Kentucky, are given in response to Mr. Bowron's frank request for cooperation on the part of those who have had opportunity to study this ore.

W. C. PHALEN.

The Copper Deposits of Missouri. By H. FOSTER BAIN and E. O. ULRICH. Bull. 267, United States Geological Survey, 1905, 50 pp.

In this report Mr. Ulrich devotes about twenty-three pages to a discussion of the Ordovician and Cambrian rocks of the Ozark

region and Mr. Bain disposes of the copper deposits in a little less than fourteen pages. The literature of the much-discussed "Magnesian series," or "Ozark series," is succinctly reviewed, the rocks described, and the classification and synonymy accepted by the authors set forth in a table.

The copper deposits, which are commercially of slight importance, are widely scattered, the principal mines being in Ste. Genevieve, Madison and Crawford counties. Most of the orebodies conform with the nearly horizontal bedding of the strata and, with the exception of the Mine La Motte deposits, they occur in those portions of the Cambro-Ordovician series which bear evidence of shallow-water deposition. Mr. Bain believes that the copper was originally disseminated unevenly through the sediments and was afterwards segregated by underground water. Chalcopyrite seems to have been the commonest sulphide, but the ores in most cases are considerably oxidized.

F. L. RANSOME.

Report on the Operation of the Coal Testing Plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904, EDWARD W. PARKER, JOSEPH A. HOLMES, MARIUS R. CAMPBELL, Committee in Charge. Part I., Introduction, by EDWARD W. PARKER; Field Work, Classification of Coals, by MARIUS R. CAMPBELL; Work of the Chemical Laboratory, by N. W. LORD, pp. 300, map and ill. Part II., Boiler Tests, by L. P. BRECKENRIDGE, pp. 681, ill. Part III., Producer Gas Tests, by ROBT. H. FERNALD; Coking Tests, by FRED W. STAMMLER; Melting Tests with Cokes, by DR. RICHARD MOLDENKE; Briquetting Tests, by JOSEPH HYDE PRATT; Washing Tests, by JOHN D. WICK, pp. 493, ill.

This bulky report gives in much detail an account of the equipment of the coal testing plant at St. Louis, the methods employed and the precautions taken to ensure accuracy in the data obtained. A preliminary statement of the more striking features of the work was published by the Survey a year ago as Bulletin No. 261, but a careful perusal of these three volumes will well repay anyone who read that bulletin.

When, early in 1904, the plans of the projected coal testing plant at the World's Fair were published and attention was called to what the plant could do for the American coal trade, the writer took occasion to point out in the *Engineering and Mining Journal* that the results obtained might have far less scientific and commercial value than the promoters of the proposed trials anticipated. He based his views on these facts: To be of any permanent scientific value, not only would the tests have to be conducted with greater thoroughness than seemed possible at a plant dependent for its equipment on the generosity of exhibitors at the Fair, but also the coals would have to represent the average output of the mines whence they came; unless there were checks by mine sampling and the inspection of coal at the tipple, some operators on the lookout for a little inexpensive advertising would ship coal to the testing plant that was a long way from being a sample of their regular output. And if the systematic sampling of a selected mine in every important coal-producing center were possible, the tonnage forwarded would be utterly beyond the capacity of the plant. Hence there was a danger that if the coals tested fairly represented the mines from which they came, the mines selected would not represent the important fields. Moreover, so far as foreign trade was concerned, the tests proposed would be of comparatively little importance since, valuable as analyses and proofs of efficiency might be for advertising purposes, other factors ruled the export trade, the chief of these being ocean freight rates and the condition and composition of the coal that the foreign consumer receives. Happily, as the event has proved, any doubts as to the permanent value of the work undertaken were not justified.

Messrs. Holmes, Parker, and Campbell, the committee in charge, found out long before the plant was completed that more coal would be offered for testing than could be handled. They also clearly perceived the importance of careful and frequent checks and the necessity of sampling the seam whence each coal was mined; and finally they recognized that the results would be of most value if attention were concentrated on the needs of the home consumer. As a result they did not attempt too much

with the equipment provided, and let the export trade look out for itself. Their choice of mines was largely, no doubt, governed by the location of the plant. Hence small mines in States that rank low as producers received attention not given the great mines of Pennsylvania, Illinois, and Ohio, but four mines in these three States being sampled for the various tests and but six carload lots of coal being received from them, though the States rank, first, second, and fourth as producers and their combined output in 1904 was 232,018,848 tons.

Whatever causes governed the selection of mines, the actual result has been most happy. For had the mines been chosen with regard to present size and value of output, three or four States would have monopolized the plant and the tests would have given results far less reliable and suggestive. In fact, it is not too much to say that as a result of the committee's care, forethought, and good judgment, their report is a unique addition to the literature of coal.

So far as the author is aware, no nation has ever undertaken to analyze under standardized conditions and compare in so many ways such a variety of coals. The German government has a testing laboratory just outside Berlin that covers a wide field of work, and the Belgian government, at Framieres, has what is probably the finest coal-mining experiment station in the world, but at neither of these places has any work been done that is in the same class with that done at the plant at St. Louis. As for Great Britain, until 1899 the leading coal-producing country of the world, practically all that has been undertaken there has been carried through by firms or by individuals with the exception of occasional steaming tests under the supervision of the Admiralty. One can find in the voluminous report of the Royal Commission information on every phase of the occurrence, mining, transportation, and use of coal, and that report, the final volume of which is yet to appear, will always be a storehouse of information to anyone interested in the coal industry of the United Kingdom and of the world. Yet valuable as is that work, it is doubtful if any such compilation of miscellaneous evidence can give the direct benefits of an investigation of narrower scope, undertaken

on a scientific basis, which shows by direct comparison under standardized conditions the relative values of different coals and emphasizes the importance of new developments in the utilization of their energy.

One fact that will gain for the work at St. Louis favorable recognition is the timeliness of the undertaking. Had the Government carried through a much more comprehensive series of tests twenty years ago, when the word inexhaustible was freely applied to all fuel supplies, and when coal was generally sold on the strength of trade names, the results would have been of less immediate utility because consumers would not have been prepared to follow out suggestions looking to the conservation of our fuel resources. As an instance of the change in public opinion may be cited the utter indifference of State Legislatures to the ruthless waste of natural gas in Ohio, Indiana, and Pennsylvania during the late 80's, when millions upon millions of cubic feet were allowed to burn in huge flambeaux for no better purpose than to promote the sale of house lots in boom towns. The geologist who foresaw and foretold the inevitable exhaustion of the underground reservoirs found his warnings fell on deaf ears. Today in most States producing natural gas, there are adequate laws for preventing waste, and the enforcement of these laws meets public approval. If a great gasser in Indian Territory roars away beyond control for a week or two, the energy wasted is commented on by the press.

As another instance of the present attitude toward fuel losses may be cited the central power stations being erected in the Pennsylvania anthracite districts, and in the bituminous fields of that State and of West Virginia. Water-tube boilers, grates for burning small coal, fuel economizers, careful insulation of steam mains, all show that even at the mines coal is not to be wasted. In fact, practically all the trusts that figure so largely in the current discussion of tendencies in production and distribution are setting an example in small economies, the conservation of what has been thrown away, that lesser corporations must follow. Hence it is absolutely certain that the endeavor to utilize to the utmost sources of energy and raw materials will

be a more and more prominent factor in the industrial life of this nation. Therefore such work as that conducted under the supervision of Messrs. Parker, Holmes, and Campbell, calling attention to the immense gains possible in the utilization of the stored energy of our coal fields has a peculiar worth not only in the actual possibilities shown, but in indicating to a public ready to make the most of these possibilities the importance of further work along the same lines and the high value of similar research in other branches of production.

It is difficult to say which of the three volumes of this report is most worthy of commendation, for all have features that call for praise, as a glance at each table of contents will show. In Part I., Mr. E. W. Parker briefly describes the conditions under which the work was undertaken, the buildings and their equipment, mentions the personnel, and summarizes some of the more striking results. Mr. Campbell gives the location and equipment of each mine visited, the geologic position of the coal seams sampled, and the methods used in sampling. He then discusses the commercial value of coal-mine sampling, based on his experience. To the writer his conclusions and particularly his proposed standard method of sampling are the least convincing of his contributions to the volume; they are discussed here at some length as the subject of coal-mine sampling has been comparatively neglected in the discussion of mine sampling generally.

Mr. Campbell states that he and three assistants from the geologic staff of the Survey sampled in all, 50 mines, the number of mines visited by each man being, respectively, 23, 16, 8, and 3. From two widely separated points in a mine a sample was taken by making a cut across the face of the seam, rejecting impurities that would be thrown out in the regular operation of the mine, and quickly breaking down the coal and quartering it to a sample that would fill a quart can. These samples were used as checks on the carloads, 20 tons, shipped from the mines for testing. From a comparison of the analyses Mr. Campbell forms some interesting conclusions. He finds that lignite and lignitic coals are apt to show a greater percentage of moisture in the car than in the mine sample; that bituminous coals containing

over 5 per cent. moisture are apt to show less moisture in the car than in the mine sample; that bituminous and semibituminous coals containing less than 5 per cent. moisture generally show a gain of moisture in the car samples; that the general average of the sulphur in all analyses shows an increase in the car sample above that in the mine sample, due to a more rigid exclusion of impurities in sampling than in mining; and that the greatest difference between mine and car samples is in the percentage of ash, the car samples showing on the average a decided gain. By dividing the sum of the percentages of moisture, sulphur or ash in the mine samples by the corresponding sum for the car samples, Mr. Campbell obtains coefficients which he thinks should be applied to the analyses of mine samples to bring them in closer accord with analyses of the probable run of shipments. He even says that the coefficients obtained in the work under his supervision are approximately correct, and suggests an arbitrary system of sampling to eliminate the personal equation. To the writer Mr. Campbell's conclusions seem based on insufficient data. Two samples from a seam in a large mine are not enough, their average may or may not represent the average coal shipped. Again, Mr. Campbell shows the character of his data when he compares the work of the several samples. His coefficients would have been quite different had the man who sampled 16 mines sampled 30, or had the man who sampled 8 sampled 40. There is nothing to show, also, that the car shipped came from the portion of the vein whence came the samples. If it did not, then the relation between the coal in the car and the coal in the mine may be accidental; if it did, the relations show the personal equation of the sampler. Again, the simple arithmetical averaging of samples is a practice that will not stand criticism. So far as moisture content is concerned his observations are highly interesting, since contained moisture can not be seen, and the personal equation of the sampler is negligible. With ash and sulphur, however, the case is quite different. What coefficients, for instance, should be applied to samples taken from several seams on a property, each seam differing in ash and sulphur content and in the way the impurities are distributed? And what

coefficients should be applied where it is proposed to mine a seam, impurities and all, and rely on some system of cleaning for getting a salable product? To the writer Mr. Campbell's automatic method of sampling, which simply rejects impurities above a certain set size and applies predetermined coefficients to the analyses, can not hope to compare with the work of an experienced engineer of ripe judgment.

Mr. Campbell's next contribution, on a proposed new classification of coals according to the ratio of the contained hydrogen of the total carbon, is highly suggestive, and an important addition to the literature of coal. He shows how Dr. Persifor Frazer's classification of bituminous, semibituminous, semianthracite, and anthracite, based on fuel ratios, that is, on the quotient obtained by dividing fixed carbon by volatile combustible matter, while it works well enough for Pennsylvania coals, groups all coals having a fuel ratio less than 5 in one class, and makes no provision for lignites. A classification based on fixed carbon alone similarly fails, while one based on calorific value, though satisfactory for lignites and the lower grades of bituminous, does not separate anthracite; hydrogen content alone is also shown to be unsatisfactory. Mr. Campbell demonstrates that the hydrogen-carbon ratio fits all the various classes of coals tested at St. Louis, and proposes a scheme containing nine groups, ranging from wood, through peat and lignite to anthracite and graphite, but plainly states that as our present knowledge of the chemical composition of coal is imperfect, any scheme of classification must be regarded as provisional. To the writer, Mr. Campbell's hydrogen-carbon ratio as a basis of classification is one of the most important scientific results of what was done at St. Louis.

Mr. N. W. Lord, in his description of the work of the chemical laboratory, gives an interesting account of the method of collecting, handling, and analyzing samples. A proximate analysis and a determination of sulphur were made on practically every sample that came into the laboratory. Ultimate and proximate analyses and determinations of calorific value were made on each car sample. Calorific value was determined by the Mahler bomb calorimeter; ultimate analyses were made in a 25-burner com-

bustion furnace, purifying trains leading to the furnace being arranged in duplicate for air and oxygen; in the absorption train the water was removed by granular calcium chloride, the carbon dioxide by potassium hydroxide. Nitrogen was determined by the regular Kjendahl method; sulphur by the Eschka method; phosphorus, in coke only, by the molybdate method. In proximate analyses moisture was determined by heating for one hour in an air bath at 105° C.; ash by heating in a crucible till all combustible matter was removed; while for volatile combustible matter the method recommended by the committee on coals of the American Chemical Society (heating 1 gram for 7 minutes in a covered platinum crucible over the full flame of a Bunsen burner) was employed. Apparently no tests of the fusibility of ash, which would have been of interest in connection with the boiler tests, were made.

The most important result of the chemical work, whether viewed from a purely scientific or from a strictly commercial standpoint, is the knowledge gained regarding the moisture content of coal. This question has been under consideration by the chemists of the Geological Survey for two years or more, and though the statement may seem surprising, has not been discussed in European technical periodicals until within a year or so. It has been shown that some coals lose moisture rapidly when finely pulverized, that some have also a marked capacity for absorbing moisture from the air, hence all moisture determinations made a few years ago, or those made today without the precautions shown to be necessary, are of slight value. A standard method requires that the moisture content of the air in the laboratory and in the drying oven itself be taken into consideration. The fineness of the sample, and the amount spread on a given area also affect the result. Of high importance to the geologist or engineer who undertakes to sample a coal seam is the demonstration that unless the samples are quartered down as quickly as possible and immediately put in hermetically sealed jars, the moisture determinations may be altogether misleading. A chemist can tell nothing about the original moisture content of a sample shipped in a box or bag.

Part II. of the committee's report is a bulky volume in which Professor L. P. Breckenridge describes the equipment of the boiler plant and the methods used in making the boiler tests, 78 in all, of which 70 are regarded as satisfactory and complete in all details. Two Heine 210-h. p. water-tube boilers, a 250-h. p. Allis-Chalmers simple Corliss engine, and a Bullock 200-k. w. direct-current generator constituted the essentials of the plant. A water rheostat was used to equalize the load on the engine. The boilers had plain grates and were hand fired. The action of the coals on the grate, the amount of clinkers formed, the amount of free ash falling through the grates, and the labor required to handle the fire successfully, were noted. The conditions of the tests made it impossible to conduct more than one test with each coal. The tests were run as nearly 10 hours as consistent with correct results, and the attempt was made to close each test with the same load, condition of fire, water level and steam pressure, as at the beginning. In calculating results the code for boiler-testing of the American Society of Mechanical Engineers was followed in all particulars. Professor Breckenridge submits the important items of the original data and observation from which calculations have been made for each test. The observations are published both in tabular form and in graphic charts. In addition, the important items and results of the 78 tests are summarized by States, so that the items of chief interest, such as rate of combustion, horse power developed, temperature of escaping gases, and evaporation per pound of efficiency, can be readily traced.

In spite of the fact that but one test could be made with each coal, yet, as Professor Breckenridge says, the opportunity to test and compare coals in the four important ways provided in these trials, the coals having been selected under known conditions at the mines, constitutes a very distinct advance in this line of investigation. It is altogether likely that the tests conducted since the close of the Exposition period with provision for at least three trials of each coal; a system of controlled draft for burning small sizes, and the use of continuous registering apparatus for the most important observations, will yield results of

even greater value to the many persons who are interested in boiler economy. Also, Professor Breckenridge expresses a wish shared by the same persons, when he hopes that future tests at the plant will include trials of several types of boilers with the same coal, the comparative efficiency of various types of automatic stokers and hand firing, the effect of forced circulation on the evaporation of a boiler, and the possibilities of powdered fuel.

Part III contains a greater variety of material than the other two volumes, and also an account of what was from a commercial standpoint the most valuable work done at St. Louis, the demonstration of the possibilities of the gas producer and gas engine in comparison with the boiler and steam engine, and, in particular, the proving of an unexpectedly high efficiency for lignites when used in the producer. This last fact opens up all manner of possibilities for cheap power in regions where the lack of high grade coals has been regarded as a barrier to industrial progress. Criticism based on present prices for producer plants and gas engines and higher depreciation charges have little weight in view of the advance in gas engine design in the past ten years.

Prof. Robt. H. Fernald, who had charge of the gas-producer tests, describes the apparatus, the methods used, and the manner of working up results. A 250-h. p. capacity Taylor pressure gas producer, and a Westinghouse vertical 3-cylinder engine were used. The engine was belted to 6-pole 175-k. w. Westinghouse direct current generator. The load on the engine was controlled by and the energy developed dissipated through water rheostats.

In all 24 different coals and lignites were used, and 22 of the tests were conducted on a 30-hour basis. Owing to the desire to test as many coals as possible, the highest efficiency was of secondary consideration, the aim being to demonstrate the possibility of using the coals in a producer. A second series of tests on the same coals with the object of securing the greatest economy will, Professor Fernald says, show a much smaller consumption of coal per horse-power hour. In the later tests 72 consecutive hours have been allowed for each, of which the first 8 to 12 were spent in studying the behavior of the coals in the producer, and securing the best possible manipulation of the plant.

In spite of the disadvantages mentioned, the data obtained by Professor Fernald in the 18 tests described are so suggestive that they are by themselves a sufficient reason for the establishment of the coal-testing plant. They are given in much detail and are thus summarized by Mr. E. W. Parker, in the introduction to Part I.:

"Bituminous coals and lignites can be used in the manufacture of producer gas and this gas may be consumed in internal-combustion engines with a fuel economy of over 50 per cent. It has been shown by comparative tests that 1 ton of coal used in the gas-producer plant has developed, on a commercial scale, as much power as 2½ tons of the same coal used under Heine boilers with a simple Corliss engine. It has been shown that a gas of higher quality can be obtained from lignite than from high-grade bituminous coals, and that 1 ton of lignite used in a gas-producer plant will yield as much power as the best Pennsylvania or West Virginia coals used under boilers."

Considering that the producer was in need of repairs during some of the tests, that it was operating under conditions which did not permit of its being manipulated to best advantage for each coal, that its adjuncts were not adapted to some of the coals, and that the gas engine was single-acting and was not provided with means for changing the ignition while in operation, criticisms based on the relative showing that might be made by a compound condensing steam engine have little weight. The tests at St. Louis are full of promise for the gas engine and indicate a longer life for our coal fields than can be determined by calculations founded on present methods of generating power.

The briquetting tests conducted under the supervision of Dr. Joseph Hyde Pratt are as valuable for their showing that certain coals can be made into briquettes on a commercial scale with the binders supplied and the equipment used, as for demonstrating that many cannot. The possibilities of the briquette fuel industry have been so often set forth by inventors and promoters with resulting financial loss to ignorant investors that an official statement is welcome. A briquette plant to utilize anthracite waste was erected at Rondout, New York, 25 years or more ago, yet

the only plants in this country which can be said to have been commercially successful, judged by their output, were those erected to briquette low-grade coal in California. Germany annually manufactures several million tons of briquettes which are used for power production and for domestic purposes. The chief drawback to the industry in this country is not so much a higher wage rate, since the labor cost can be minimized by automatic machinery, as the high price of suitable binders. In Germany, where the by-product coke oven is the prevailing type and the utilization of by-products is carefully studied, suitable pitch can be cheaply had—also the so-called magnesia cement, a by-product of the great Stassfurth potash salts industry. Another barrier to the growth of an American briquette trade has been the comparatively low price of excellent coal in the densely settled sections of this country. The experiments conducted by Doctor Pratt, using an English and an American briquette machine, showed very clearly the behavior of different coals and the importance of obtaining suitable binders. In fact, commercially successful briquetting means certain methods and certain binders for certain coals. A positive result of the St. Louis tests was the demonstration of the possibility of utilizing on a commercial scale the slack, now largely wasted from the dry non-coking coals of the Middle West, and from the semi-anthracite coals of Arkansas. It is to be regretted that the equipment of the washing plant did not permit of more convincing tests with washed coals. Tests to determine the possibility of making merchantable coke in a beehive oven from briquettes were not conclusive.

Perhaps the least satisfactory work at St. Louis, considering the opportunity, was with the washing plant and the coke ovens. Messrs. John D. Wick and Fred W. Stammler did all that could have been expected of them under the circumstances, but the equipment at their disposal was not nearly as complete as it would have been had the commissioners been able to purchase apparatus. The washing plant consisted of two jigs, the coking plant of beehive ovens. Now, the working of impure coal seams and the subsequent purification of the coal are matters of great and growing importance; the capacity of by-product ovens, whether of the

Semet-Solvay, Otto-Hoffman, or other types, to make good coke out of washed coals that will not coke in a beehive oven, is a subject calling for attention. The two investigations could have been carried out to better advantage at St. Louis than at almost any other point, because the benefaction of impure coals by washing and their subsequent use in the by-product oven, are matters of greater importance to the West than to regions near the remarkable coking coal seams of the Appalachian fields. It is much to be regretted that at a plant where such systematic and painstaking work was done, better equipment could not be had. If the washing plant had included jigs of the Baum type, which have met such favor in Europe, bumping tables of the Campbell pattern, that have been installed at the largest coal-washing plant in this country, and friction separators that are used at anthracite mines, and are being tried at bituminous mines, the results would have been of very great value to the American coal industry. The jigs installed did, indeed, show that certain coals were benefited by their use, but coals vary not only in the ash and sulphur content, but in the manner those impurities are distributed, and to purify some coals such fine crushing is necessary that jigs of the types tested at St. Louis are not the most economical devices. With provision for washing very fine coals, experiments to determine the distribution of sulphur in different coals, whether chemically combined, or as thin flakes along joints, or as aggregations of some size, say above one tenth inch, would have yielded highly instructive data. In fact, the subject of coal washing calls for comparative tests under standardized conditions with devices of quite different types. Such work can be undertaken by private corporations of large means, but it is not likely that any corporation will in the near future test such a variety of coals as were available at St. Louis.

In conclusion, the writer states his belief that the chief value of the work so ably carried out under the supervision of Messrs. Parker, Holmes, and Campbell is its demonstration of the importance of standardization. Done at a time when the public is coming to realize the utility of waste prevention and the commercial value of small economies, it sets a standard for other tests,

not only of fuels but of materials of construction, which can be undertaken to better advantage and to the greater benefit of the public under government supervision than by an individual or by a corporation or combination of corporations.

SAMUEL SANFORD.

Juvenile and Vadose Springs. By DR. RUDOLPH DELKESKAMP. Balneologische Zeitung, Vol. XVI., No. 5, February, 1905.

By the same author:

Die Bedeutung der Geologie für die Balneologie. Zeitschrift für praktische Geologie, Vol. XII., June, 1904.

Die Genesis der Thermalquellen von Ems, Wiesbaden und Kreuznach und ihre Beziehungen zu den Erz- und Mineralgängen des Taunus und der Pfalz. Paper read at the meeting of the Deutsche Naturforscher und Aerzte, September, 1903. Cassel.

Vadose und juvenile Kohlensäure. Zeitschrift für praktische Geologie, Vol. XIV., February, 1906, pp. 33–47.

The theory of juvenile waters has found an ardent and able exponent in Dr. Rudolph Delkeskamp, who has expressed his views in the several scientific or semi-popular papers mentioned above. The author acknowledges his debt to the brilliant work of Professor Suess, who first presented this theory in modern form to European men of science in 1902, when he advocated a juvenile origin for the Carlsbad Springs, and thereby gave the impetus to renewed research in this direction.

The old theory of the circulation of water in the earth's crust, apparently so simple and natural, is unable to solve the problem of mineral springs. Doubts were expressed years ago by well-known French authors, among whom Elie de Beaumont was the most prominent, and the genetic connection of thermal springs with eruptive rocks and metalliferous veins was clearly expressed. In its more modern form the theory of juvenile waters (a fortunate term coined by Professor Suess) states that atmospheric precipitation does not supply the water for all springs. Many springs are indeed entirely "vadose."[1] Their water is con-

[1] Vadose is a term adopted by Posepny to designate surface waters, infiltrated in the upper crust from atmospheric precipitation (vadus = shallow). Suess designates all of the water belonging to the atmosphere and hydrosphere as vadose.

densed as clouds, which falls as rain on the earth, is absorbed by the rocks and finally again reaches the surface of the earth as ascending springs, obeying the principle of hydrostatic pressure.

In contradistinction to these, juvenile springs appear newly born from the depths of the earth and their water is derived from the igneous magmas of which they once formed an integral part. They issue to form a permanent addition to the hydrosphere, while their dissolved gases and salts likewise increase the atmosphere and the mineral substance of the crust.

This division of springs as juvenile and vadose is a classification according to origin. Another principle of classification, applied for many years, has as a basis the chemical composition of the waters, either according to mineral salts or according to the more correct and modern views of ionization or dissociation of salts in dilute solutions.

The vadose springs fed by rain water, and deriving their salts from the region of sedimentary and crystalline rocks, vary in quantity of water and in the quantity of the dissolved salts. The juvenile springs, on the other hand, have the same concentration and produce the same amount of water during the different seasons.

The water, as well as the salts dissolved in it is juvenile. Both are products of eruptive after-effects, which also form solfataras, exhalations of carbondioxide, and steam, and which, in many cases, are believed to be responsible for the filling of mineral veins.

In past geological times igneous masses were forced up from the interior of the earth. In places they could not overcome the enormous pressure of the overlying beds. Instead of reaching the surface they bulged up the sedimentary beds and solidified as laccoliths. During the crystallization by slow colding the water contained in the magma was separated from the silicates. Together with the water were separated all such substances which, at the temperature prevailing at the time, were more soluble in this water than in the silicate magma. To these substances belong sulphuretted hydrogen, carbondioxide, combinations of the

univalent ions, chlorine, fluorine, and boron, with alkaline earths and alkalies, partly also silica. The ions of the bivalent metals, such as iron, zinc, lead, copper and tin appear to prefer to follow the negative ions.

Successively separated masses of water collect and occupy the upper surface of the intrusive body until they finally ascend at points of least resistance, such as fissures in the rocks overlying the magma.

According to the view here explained, the increase of temperature and the fissuring of the rocks in volcanic regions is not the cause of thermal springs appearing so often in igneous districts. It is held, on the contrary, that the volcanic action is the direct cause of the thermal springs, for the water and dissolved salts have been derived directly from the igneous rocks. According to the theory of Kant and Laplace, the magma contains water as an essential constituent. The cosmic vapor, from which the earth was created, was composed of an association of the different elements in gaseous state. By cooling in cold space this gas was condensed until finally a solid crust enclosed the highly compressed gases. These gases necessarily still contain all the elements which from the beginning entered into the composition of the cosmic vapors. The immense masses of steam which escaped during volcanic eruptions from the ascending lavas indicate clearly that water was derived from the magma.

If the waters of volcanic eruptions are considered as juvenile, it is necessary to prove that the volcanic magma actually contains included or dissolved water. The analysis of crystalline volcanic rocks does not always give us the desired data, for during the crystallization the water is usually expelled. The volcanic glasses, however, which have consolidated rapidly and under high pressure often contain an average of from 5 to 8 per cent. of water, and furnish clear evidence of the primary contents of water in the volcanic magma.

The gaseous and liquid exhalations of the volcanic centers form on their way to the surface of the earth many kinds of deposits, among them mineral veins. It is characteristic of juvenile springs that we find in their vicinity igneous rocks, fissures, and mineral veins.

According to the author the following factors are of importance for the classification of springs:

1. *Temperature.*—This is not in itself a decisive evidence of origin, for the paths followed by the water may be devious and complicated. Differences in temperature among springs of the same group may be explained by different roads travelled by the waters and by mixture with cold vadose water. In the case of the springs of Ragaz-Pfäffers, the temperature of which is 37° C., the water is probably wholly vadose.

2. *Salinity.*—The salinity of springs is not in itself decisive evidence as to their origin. It has been shown that many metals are present in eruptive and sedimentary rocks in small quantities, It is, therefore, possible that the springs of purely vadose origin may carry comparatively rare elements. The vadose spring of Pfäffers contains, according to Treadwell, boric acid, arsenic acid, fluorine, and traces of copper, thallium, rubidium, and cesium.

3. *Dissolved Gases.*—Gases contained dissolved in spring waters may occasionally be of vadose origin. Hydrogen sulphide and hydrocarbons are often of such origin. Even carbon-dioxide may occasionally be vadose, but when the gas has this origin it seldom mingles in large amounts with ascending saline waters, although this may take place to some extent when the waters traverse sedimentary beds containing organic substance. A saline solution and carbondioxide are very slowly miscible and a long time is needed before large amounts of such solutions can be impregnated with gas.

Safer criteria for deciding the origin of springs are afforded by variations in the contents of salts and gases. The constancy of the degree of solution is best established by the fact of equal concentration during years of very different precipitation. In case of mixed vadose and juvenile springs the juvenile origin of certain constituents may be recognized in their constant relative proportion. If it can be shown that changes in the composition and concentration are related to changes in the amount of precipitation, it may be accepted as certain that the springs are at least strongly admixed with waters from the vadose circulation. Carbon-dioxide is in the majority of cases juvenile.

The juvenile nature of a spring is suggested by the presence of metals such as copper, nickel, cobalt, arsenic, antimony, tin, lead and zinc, and those substances which indicate the hottest phase of volcanic exhalations, such as boron, fluorine, chlorine, iodine and bromine.

The majority of springs are doubtless purely vadose; a smaller number are purely juvenile, and a large proportion is assuredly of mixed origin.

In case of the Carlsbad springs, Professor Suess has shown the wholly juvenile origin of the salts, the water, and the carbon dioxide. Equally certain is the vadose nature of the springs of Ragaz-Pfäffers in Austria, which have a temperature of + 3685° C. Alpine lakes in the neighboring mountains of the Graue Hoerner are in all probability the areas of infiltration for these springs. Their elevation is from 2,032 to 2,396 meters. The thermal water is an extremely dilute solution containing .295 grams to the liter and issues from Tertiary beds in an approximate elevation of 800 meters, consequently from 1,232 to 1,596 meters below the probable origin. The quantity of water changes considerably according to the precipitation and increases annually during the melting of the snows.

The data acquired in driving the great railroad tunnels of the world have shown that the geoisothermal lines approximately conform to the surface of the mountains. Assuming a geothermal increment of 1° in 30 in meters the mentioned difference in elevation would apparently suffice to permit the waters to acquire a temperature of 36.9° at the issuing point.

The springs of Baden, in Switzerland, seem also to be of exclusively vadose origin. At this place twenty-one springs issue with a temperature of + 49° C. and have nearly identical composition. They differ in quantity of water issuing during successive years, and this difference may be from 8 to 40 per cent. of the average quantity. The springs rise from an anticlinal at the place where the Triassic rocks are cut transversely to the strike by the River Limmat.

Juvenile springs may also issue at the surface with low temperatures. In such case they represent the last phases of the

eruptive activity and will probably wholly disappear in short time, geologically speaking. Good examples of such kind are afforded by the springs of Marienbad, which are cold. Their juvenile relationships can only be shown in their genetic connection with mineral deposits and igneous rocks.

As the pressure from below diminishes the solutions are more likely to turn into by-ways and permeate the fissured rocks in the lower part of the crust, where it finds abundant opportunity for leaching and metamorphism. In these by-ways chances are given to mix with other juvenile waters and—in the vadose zone—with ascending vadose springs. The temperature, concentration, and general composition is now changing, but such changes are very gradual and only rarely to be observed during periods of a few years.

Many places which now only have comparatively small springs were formerly the scene of great thermal activity; it was thus, for instance, at Carlsbad in Bohemia.

The association of minerals in metalliferous veins shows clearly the intermittent and changing nature of thermal infiltration. Differences in the primary nature and composition of veins at varying depths and transitions between several types of veins illustrates the several phases of post-volcanic processes. The observations at volcanoes have shown a dependence of the exhaled substances on the temperature.

The earliest phase of volcanic exhalations is distinguished by the presence of fluorine, arsenic, phosphorus, boron, tin, bismuth, copper, iron and manganese. In second phase appear hydrogen sulphide, sulphur dioxide, with other sulphides and bases. The third phase is marked by the presence of carbon dioxide.

The intensity of the eruptive after-effects decreases slowly after the close of the actual igneous activity. It follows from this that in juvenile springs also a very slow change of temperature and concentration takes place. The non-vadose cold springs containing carbon dioxide show the last phase of the juvenile waters. The diminishing pressure greatly increases the facilities of admixture by vadose waters.

Juvenile waters, or mixed juvenile and vadose waters, will thus gradually become purely vadose. Gradually there will be developed a dependence on a basin of precipitation, and the volume of water will increase or decrease with the precipitation of successive years. The influence of the precipitation in the catchment area is not always apparent in the spring at once. Retardation may take place which ordinarily is proportional to the depth of the vadose circulation. This retardation may amount to half a year, so that periods of maximum precipitation coincide with minimum flow of the spring.

A good example of the mingling of vadose waters with juvenile is offered by the Iron Spring at Ems. This spring contains .0414 grams of alkaline sulphates corresponding to 8.07 per cent. of total solids, while at the other springs of Ems 1.3 and 2.4 is the highest percentage known. This alkaline sulphate is the product of decomposition of the sulphates in a descending vadose spring percolating through pyritic shales by means of the sodic carbonate in the ascending thermal water. The surface water seeping through the pyritic shales leaches from them sulphates of iron, aluminum, and other metals, further, chloride of sodium and carbonate of lime. By diffusion with the thermal water alumina is precipitated with formation of alkaline sulphates. Ferrous oxide and manganese oxide combine with the carbon dioxide and are dissolved as carbonates, while the substances which take no part in these reactions remain dissolved in the mineral water resulting from the mixture.

The constancy of composition of juvenile waters is well illustrated by the springs of Wiesbaden. During a period of 36 years, from 1849 to 1885, while Professor Fresenius was in charge of the Kochbrunnenspring at Wiesbaden, 59,640 kil. of solid constituents were carried up with the water. The variations established by Fresenius are shown in the following table:

VARIATION OF TOTAL SOLIDS IN SOLUTION.

Spring.	Temperature.	Maximum Variation Per Cent.
Niederselters,	15.5 C.	12.7
Kesselbrunnen (Ems),	47 C.	1.1
Kranchen (Ems),	36 C.	4.1
Kochbrunnen (Wiesbaden),	68.5	.3

Professor Fresenius concluded from this that springs of highest temperature show in general least variation in total solids, and added that the conditions of origin might well be supposed to be on a greater scale in case of hot springs of deep-seated origin than in cold springs, in which a dependence on local and atmospheric conditions would be more clearly manifest.

In general, this theory of Fresenius holds good, but not in all cases, for the temperature of the water is not absolute proof of its juvenile origin.

Temperature, salinity, artesian pressure and quantity of water are not conclusive. The variation in the relative amount of salts is the only safe criterion to distinguish juvenile from vadose waters.

The most important regions of thermal activity coincide with the principal centers of volcanic eruptions, as illustrated by the conditions in the Yellowstone Park, the Eifel Mountains, northern Bohemia, the Roehn Mountains, and the Vogelsberg.

The author finally discusses the linear grouping of springs which is not uncommonly observed and believes that this is due to fissures or zones of crushing in the crust; these dislocations may not always be clearly visible at the surface.

In the third paper, Dr. Delkeskamp describes the springs of three important thermal districts.

The springs of Ems issue from an anticlinal of quartzite on a network of joints instead of on single fissures. The author believes that they are juvenile and that they are derived from a single volcanic focus. The relative amounts of substances dissolved are very similar in the various springs and their difference in temperature is to be explained by more or less devious ascending paths. Among the contents of the waters are sulphur, copper, lead, arsenic, barium and silica; this connects them with the mineral veins of the "pyritic lead formation" so greatly developed in the valley of the Lahn. In fact, the springs issue in the prolongation of the cupriferous vein of Neuhoffnung-Stollen which cuts transversely through the quartzite anticlinal. Basaltic rocks appear close by.

Wiesbaden. The thermal springs of Wiesbaden issue from a schistose sericite-gneiss at a place where it is cut by parallel northeasterly coursing quartz veins. The principal line of springs form a thermal line parallel to the strike of the gneiss.

Fresenius has established the fact that these springs are practically constant in their mineral contents, the analyses extending over a long period of seasons and years. The author considers that their juvenile nature is firmly established by this fact. The differences of the individual springs in salinity and temperature is not due to admixture of vadose waters. The contents of the thermal springs in chlorine, sulphur, silica, carbondioxide, aluminium, barium, copper, phosphorus, arsenic, and bromine suggests a connection with ore-forming processes. Pseudomorphic calcite-barite veins are widely distributed in the district and seem to be connected with the quartz vein of the Nero valley which contains some tetrahedrite. Basaltic eruptions occur in the vicinity. The thermal springs have been active since the middle part of the quaternary and may have existed since Tertiary times.

The springs of Kreutznach issue in the valley of the Nahe and the author believes, on ground of a careful study of analyses, that the waters are clearly influenced by vadose circulation. The old views of Bischof, Laspeyres, and Dunker, according to which the springs should contain the products of leaching of porphyry, melaphyr, or the "Rothliegende" beds are not believed to be correct, as many substances in the springs can not be found by analysis in these rocks.

The springs issue in a structural valley eroded in porphyry and are arranged in linear form. Many fissure veins containing copper, quicksilver, calcite, barite, and fluorite, appear in the immediate vicinity and their connection with the thermal phenomena seems most probable.

Old sinter deposits in the middle oligocene on the porphyry hills contain barite and show that here, as at Baden-Baden, Carlsbad, Wiesbaden, and Ems the waters once issued at a higher level. An exact determination of age is not possible. The springs lack entirely in sulphates and the earlier deposits of barite. This

must, therefore, be explained by very gradual changes in the composition of the water.

The springs of Kreutznach show strong vadose influence, but it is believed that they were once wholly juvenile. The contents of chloride of sodium is derived from Permian beds sunk in the " graben " of the valley of the Nahe.

In the last mentioned paper the author gives an exhaustive review of the origin of the carbondioxide in mineral waters. His conclusions are that large amounts of this gas are given off from vadose sources, but that the volumes of carbondioxide of juvenile origin are " enormous." Among the processes of vadose origin, he recognizes development from coal beds and peat deposits. The gas may also be generated from limestone by the action of sulphuric acid derived from oxidizing pyrite, by heat alone if opportunity is given for the gas to escape, or by the reaction of hot solutions of silica—for instance, during contact metamorphism. Absorption of carbon-dioxide from the atmosphere is also mentioned. All these processes are local and quantitatively insufficient; it is impossible to assume that there is a coal bed or a stratum of limestone underneath every spring carrying carbon-dioxide. If the view of derivation from limestone were true in case of carbon-dioxide given off by volcanoes, we should expect that its most intense period of generation should correspond with the principal phase of igneous activity, whereas in fact the gas appears in largest volume after the eruption.

Most of the carbon-dioxide must be of juvenile origin; it was dissolved in the magma, and separated during its consolidation. This view is substantiated by a detailed review of the literature on volcanic eruptions and the constitution of the magma, and gives a good survey over the real state of search in this branch of science. To some extent the gas may be derived from inclusions of liquid carbon-dioxide in the quartz grains of granites and porphyries, and set free by crushing or heat, but the author is justly inclined to question the importance of this process; it adds a certain amount all along to the atmosphere by normal rock decomposition, but this amount is probably very small.

A recent abstract of a lecture by Dr. Grünhut, in Wiesbaden,[2] indicates that the views of Dr. Delkeskamp on juvenile springs have not as yet found universal acceptance. Dr. Grünhut believes in the vadose origin of the springs in the region of the middle Rhine, including those of Wiesbaden, and considers that the hottest of these (+ 64° C.) is fed by atmospheric waters descending to a depth of 6,600 feet.

W. LINDGREN.

The Copper Deposits of the Clifton-Morenci District, Arizona. By WALDEMAR LINDGREN. Professional Paper No. 43, United States Geological Survey, pp. 375, Plates I.–XXV. (including map in pocket) and 19 figures in the text. Washington, 1905.

Clifton, which as a copper center ranks next to Bisbee in productiveness, is situated near the eastern boundary of Arizona, about 60 miles north of the main line of the Southern Pacific. The oldest rocks in the district are pre-Cambrian granite and quartzitic schists, separated by a great unconformity from 1,500 feet of overlying Paleozoic strata which are in turn unconformably overlain by Cretaceous sediments. All these rocks are cut by stocks, dikes and sheets of granitic and dioritic porphyries. After the intrusions, in late Cretaceous or earliest Tertiary time, the region was domed and faulted. It was afterwards covered by enormous flows of Tertiary lavas, which have since been eroded from the central part of the district, their detritus contributing to the formation of an extensive Quaternary fluviatile deposit known as the Gila conglomerate.

The intrusion of the granite-porphyry effected intense alteration of the adjacent rocks, particularly of the pure Paleozoic limestones, as shown by the development of garnet, epidote, pyroxene, amphibole, magnetite, hematite, pyrite, chalcopyrite and sphalerite, the alteration extending in some places to a distance of 2,000 feet from the eruptive rock. This metamorphism is very thoroughly described by Mr. Lindgren who shows convincingly that the altered rocks have received a great accession (up to 40 per cent.) of silica, iron, sulphur, copper, and zinc. Quite inde-

[2] *Zeitschr. für prakt. Geologie,* Vol. XIV., March, 1906, p. 95.

pendently of its bearing on ore genesis, the establishment of this fact is an important contribution to the general subject of contact metamorphism and shows that petrographers have extended too broadly the conclusion, drawn from certain classic examples, that contact metamorphism involves only slight change in substance.

Once granted that a solidifying intrusive mass may give off sufficient material at high temperature to compensate for the carbon dioxide expelled from neighboring beds of limestone by the heat and chemical energy of the intrusion, the genesis of such ore deposits as those of Clifton constitutes merely a special problem in contact metamorphism. Mr. Lindgren concludes that the copper deposits of Clifton and Morenci were "formed primarily by mineral-laden magmatic waters, partly acting as gas and partly as liquids, and in both cases derived from a magma of granite-porphyry."

The primary ore deposits fall into two main classes: (1) Irregular or tabular disseminations in limestone or shale, and (2) fissure veins. The former are typical contact deposits, completed before the consolidation of the porphyry. The latter were formed after the solidification of the upper part of the intrusive body by hot ascending magmatic waters. That the solutions were hot and that they were similar in at least some of their constituents to the magmatic water of the granite-porphyry are shown by a most interesting and suggestive study of the liquid inclusions in the vein quartz and in the quartz phenocrysts of the porphyry. This study proves that the granite-porphyry magma held notable quantities of water in which was dissolved a salt, probably sodium chloride, and smaller amounts of "some compound containing one or several of the heavy metals." Furthermore, the vein-depositing solutions have in some cases produced tremolite, diopside and epidote by metasomatic action on the wall rock—minerals rarely found in genetic connection with fissure veins although rather characteristic of contact metamorphism in limestones.

Although Mr. Lindgren expressly states that his conclusions

do not necessarily apply to deposits outside of the Clifton district, one reviewer of his work has announced that whatever theory of genesis fits the Clifton ores must be equally applicable to those of Bisbee. The latter deposits, however, are not accompanied by the conspicuous and intense contact metamorphism so well described by Mr. Lindgren, the alteration of the limestone resembling more closely that associated with certain of the fissure veins of Morenci and Metcalf. The porphyry masses exposed near the ore bodies at Bisbee are much smaller than those at Clifton and are themselves extensively pyritized and sericitized. The Bisbee deposits thus, as regards metasomatic action, stand between those of Globe which are certainly not due to contact metamorphism, and those of Clifton where the relation between ore deposition and igneous intrusion now admits of no question. In the light of Mr. Lindgren's results the present reviewer is quite prepared to admit (what indeed he has never denied) the possibility that the Bisbee ores may have emanated originally from a deep-seated body of granite-porphyry magma, but possibility is not proof and Bisbee certainly offers no such cogent evidence in favor of magmatic emanations as Mr. Lindgren has so ably marshalled in support of his thesis at Clifton.

Neither the contact deposits nor fissure veins, as originally formed, were rich enough to work under present conditions. As at Globe and Bisbee the final concentration has been effected by generally descending meteoric water, pyrite and chalcopyrite being oxidized to ferrous and cupric sulphates, with free sulphuric acid, and these reacting on the deeper sulphides to form chalcocite which is the principal mineral of the sulphide ores mined. The process is an actual replacement of pyrite and sphalerite by chalcocite.

At depths of 500 feet or less the chalcocite zone changes with remarkable abruptness to low-grade pyritic ores. Its formation is thought to have corresponded to a period when the groundwater stood much higher than at present, as must have been the case during the deposition of the Gila conglomerate and in Tertiary time. The final change of the chalcocite zone to cuprite, native copper, malachite, brochantite and other oxysalts proceeds

very irregularly downward from the surface, oxidation having been left far behind by the general subsidence of the groundwater since early Quaternary time. The entire process of enrichment and oxidation by descending atmospheric water is admirably described and its chemistry carefully and suggestively discussed. The formation of ore bodies by the migration of sulphate solutions into permeable limestones and shales is an interesting feature of the Clifton-Morenci district and recalls certain chrysocolla deposits, of probably similar origin, in tuff at Globe, Arizona.

The mineralogy is very satisfactorily treated. Eight or nine ore minerals are recorded from this district for the first time; one, libethinite, was new to the United States, though it has since been noted in Nevada, and two, morencite and coronadite, are new species. Brochantite is shown to be a far more important ore mineral than had been supposed, having often been confounded with malachite. The excellent account of metasomatic processes, a field that Mr. Lindgren has made particularly his own, is supplemented by several effective photomicrographs, showing successive stages of alteration.

To arrange in the most clear and effective way a work so rich in material as the one before us is no easy task, and few geologists are willing to concede to manner more than a very small fraction of the labor devoted to matter. In the present case a lack of unity appears in some of the chapters, and chapter V. in particular contains some sections which seem out of their logical positions. Fortunately these defects in arrangement, which render it a little difficult at times to turn quickly to subjects sought, are partly atoned for by excellent summaries.

The illustrations are well chosen and the numerous carefully drawn sections of mines add much to the descriptions. It is unfortunate, however, that, in a report which is not over-illustrated, an exigeant policy of economy should have required the reproduction of the geological structure-sections as black and white text figures instead of as chromolithographs on the same sheets as the maps to which they pertain.

F. L. RANSOME.

Records of the Geological Survey of India. Vol. XXXII., Part 2, 1905. Calcutta, 1905. Pp. 188, with map.

This brochure contains a "General Report of the Geological Survey of India for the period April, 1903, to December, 1904," by T. H. Holland, director; a "Preliminary Note on the Geology of the Provinces of Tsang and Ü in Tibet," by H. H. Hayden; and a paper on "The Occurrence of Bauxite in India," by T. H. Holland.

The director's summary is a readable account of scientific investigations recently published or in progress. Among the latter the studies of Mr. L. L. Fermor on the increasingly important deposits of manganese ores in the central provinces promise much of interest. The ore bodies are essentially lenticular masses of braunite in pre-Cambrian gneisses, schists and quartzites. They seem to have resulted from the alteration of manganiferous silicates, notably spessartite, rhodonite and manganese pyroxenes. Some of these silicates, including some remarkable pleochroic pyroxenes and a crimson manganiferous mica, appear to be minerals new to science, and several others have not hitherto been recorded from India. Most of the deposits occur near the edge of the great Deccan trap flows and it is suggested that there may be some connection between the alteration of the silicates to oxides and a former covering of trap.

A comprehensive investigation of the salt resources of the large saline lake at Sambhar in Rajputana is also in progress. The silt in this lake is from sixty to eighty feet deep and contains enormous quantities of sodium chloride, a preliminary estimate giving a million tons per square mile in the upper twelve feet of the deposit.

The discovery is announced of some interesting nephelite and sodalite syenites near Kishengarh, in Rajputana and progress is recorded in various important investigations in structural geology and in paleontology.

Mr. Hayden's reconnaissance in Tibet, as geologist attached to the expedition under Col. Younghusband, revealed an extensive terrane of fossiliferous Jurassic rocks, stretching from the Him-

alayas far to the north of Lhasa, and associated with some Cretaceous and Tertiary beds. The region is said to be very deficient in mineral resources, although a little gold was panned from the gravels of the Brahmaputra, south of Lhasa.

The high percentage of alumina in some of the peculiar weathered product of the Deccan trap, known as laterite, was first noted by Mr. F. R. Mallet in 1883. Following up this suggestion, the present director and his staff have shown that at numerous localities the laterite carries as much alumina as the high-grade bauxites of France and America. While it is yet doubtful whether the material can be mined and exported in competition with the bauxites of more favored localities, the deposits seem to be of vast extent and will doubtless become available in the future. In the meantime their study promises to throw light on the geological conditions under which bauxite accumulates or forms.

F. L. RANSOME.

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SCIENTIFIC NOTES AND NEWS[1]

MR. HORACE V. WINCHELL, for the past eight years in charge of the geological department of the amalgamated copper interests in Butte, has accepted an appointment as chief geologist for the Great Northern Railway Company. His address is now St. Paul, Minnesota.

A REVIEW RECENTLY APPEARED in ECONOMIC GEOLOGY (Vol. I., No. 2, pp. 175 to 182) on the "Geology of South Africa," by F. H. Hatch and Geo. S. Corstorphine. The authors of the book have called the attention of the editor to a statement made in this review which it is the desire of the reviewer to here correct, as it may be somewhat misleading. On page 179, in the discussion of the Witwatersrand conglomerates, it is stated that "the extended experience of Mr. Hatch in petrographical work renders this discussion extremely valuable." This statement would appear to signify that Mr. Hatch alone is entitled to credit for this portion of the book, whereas in the treatment of this subject as in all portions of the work, Mr. Corstorphine and Mr. Hatch were collaborators and are entitled to an equal measure of credit for their work.

MR. W. D. CAMPBELL, of the staff of the Geological Survey of Western Australia, has just completed a detailed geological and topographical survey of the Norseman district, in the Dundas goldfield. The area embraced by the survey covers about forty-six square miles. The staple formation of the district consists of about 800 feet of highly inclined metamorphosed sedimentary rocks (of the geological age of which the district affords no clue), associated with a series of basic igneous rocks, some of

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

which are intrusive, and the rest imbedded with the ancient sediments. These beds are invaded by a network of acidic dykes, and a much newer norite, which crosses the auriferous series at right angles to its general strike. The district has proved a good mining field, the auriferous quartz reefs being scattered over a large area of country, and in some cases attain a very large size. Since its first discovery a few years ago the Norseman field has yielded over a quarter of a million of gross ounces of gold. The geological map is accompanied by five large mining plans, and twelve sections of mines, on the scale of 100 feet per inch. A report upon the geology and mines of the district is now in the press.

MR. M. L. FULLER, of the Division of Hydrology of the United States Geological Survey, gave a course of lectures at the University of Chicago during the week of April 2 on the hydrographic and hydrologic work of the Survey, including stream measurements, flood studies, studies of underground waters, investigations relating to the quality and uses of water, and the engineering work of the Reclamation Service.

AT THE COMMENCEMENT EXERCISES of the University of Nevada, May 31, 1906, President Stubbs announced that Clarence H. Mackay and his mother, Mrs. John W. Mackay, have together given $50,000 for the immediate erection of a building for the School of Mines. This building is to house the Department of Mining and Metallurgy and that of Geology and Mineralogy and has been planned according to the recommendations of the heads of these departments. A recent State appropriation for the Metallurgical laboratory with a new ore-treating equipment. which will be suitable for installing in the new quarters. The building will also contain a geological museum which is intended to care for the present collections that are now largely stored away on account of lack of room. With the opportunity for proper care and display of specimens, it is planned to develop rapidly a collection representing as completely as possible the mineral resources of the State whose chief asset is its mineral wealth.

Furthermore, Mr. F. M. Smith has arranged to provide a perpetual income of $1,000 a year, to be used for the support and encouragement of students in the Mining School. This will, in general, be divided into five annual scholarships of $200 each, to be known as the F. M. Smith scholarships and open to deserving students irrespective of citizenship or residence. As tuition is free and as board and room may be obtained at the dormitory for $150 for the college year, these will provide for most, and, in some cases, all, of a student's necessary expenses.

W. E. McCOURT, A.M., instructor in practical geology and mineralogy in Cornell University, has been appointed instructor in geology, in charge of the department at Washington University, St. Louis.

H. LEIGHTON, assistant in economic geology in Cornell University, has been promoted to an instructorship in the same institution.

MR. A. F. CRIDER, formerly a member of the United States Geological Survey, has accepted an appointment as State geologist of Mississippi. The first work which will be undertaken is the investigation of resources of clay, lignite and cement material.

MR. G. K. GILBERT, of the Geological Survey, and a member of the State Commission on the San Francisco earthquake, has recently returned from California. He gave an informal discussion of the earthquake before the members of the Survey a few weeks ago.

NATHANIEL SOUTHGATE SHALER, S.D., LL.D., professor of geology and dean of the Lawrence Scientific School, died in Cambridge April 10, 1906, after more than forty years of faithful work at Harvard.

Professor Shaler's remarkable personality made a profound impression on the college and the community. The names of over 6,000 students have been enrolled in his classes. In recognition of his great services to the University, the Executive Committee of the Alumni Association has appointed a general committee to secure a Shaler Memorial Fund—the form of the memorial and the depository of the principal and income of the

fund to be determined by the committee. Graduates of Harvard College or the Scientific School who desire to contribute to the fund should send their subscriptions to Edward W. Atkinson, chairman of committee on Shaler Memorial, 152 Congress St., Boston, Mass.